CALIFORNIA ENERGY COMMISSION

Integrated Ceiling Research Report

Integrated Ceiling Research Report (product 5.4.2)

TECHNICAL REPORT

October 2003
500-03-082-A-28

Gray Davis, *Governor*

CALIFORNIA ENERGY COMMISSION

Prepared By:
Heschong Mahone Group
Jon McHugh, Lead Author
Fair Oaks, California

Managed By:
New Buildings Institute
Cathy Higgins, ***Program Director***
White Salmon, Washington
CEC Contract No. 400-99-013

Prepared For:
Donald Aumann,
Contract Manager

Nancy Jenkins,
PIER Buildings Program Manager

Terry Surles,
PIER Program Director

Robert L. Therkelsen
Executive Director

ACKNOWLEDGEMENTS

The products and outcomes presented in this report are part of the **Integrated Design of Commercial Building Ceiling Systems** research project. The reports are a result of funding provided by the California Energy Commission's Public Interest Energy Research (PIER) program on behalf of the citizens of California. Heschong Mahone Group would like to acknowledge the support and contributions of the individuals below:

Heschong Mahone Group, Inc.: Principal in Charge: Lisa Heschong. Project Director: Jon McHugh. Project staff: Puja Manglani and Rocelyn Dee.

Subcontractors: Jack A. Paddon and James L. Engler of Williams + Paddon Architects + Planners Inc., Marshall Hemphill of Hemphill Interior technologies, and James Benya of Benya Lighting Design.

Review and Advisory Committee: We are greatly appreciative of the following people who contributed to the review of this report: William Beakes of Armstrong Industries, Jerry Blomberg of Sunoptics, Pete Guisasola of City of Rocklin Building Department, Rob Samish of Lionakis Beaumont Design Group, Michael White of Johnson Controls, Chuck McDonald of USG, John Lawton of Velux, John Mors of Daylite Company, Joel Loveland of Lighting Design Lab, Anthony Antonelli of Ecophon, Steve Fuller and Martin Powell of Albertsons, Jehad Rizkallah of Stop and Shop, Paul McConocha of Federated Departments, JimVan Dame of My-Lite Daylighting Systems and Products, Doug Gehring of Celotex, Ivan Johnson of TriStar Skylights, Robert Westfall of Solatube International Inc., Leo Johnson of PJHM Architects, George Loisos of Loisos/Ubbelohde Architects, Jim Kobs of Chicago Metallics, Steve Ritcher of Crystollite, Jackie Stevens of So-Luminaire, Peter Turnbull of PG & E, Sean Flanigan of WASCO Products, Richard Schoen of Southern California Roofing, Mike Toman and Jeff Guth of Ralphs and Food for Less, and Lori Johnson of Target.

Project Management: Cathy Higgins, New Buildings Institute; Don Aumann, California Energy Commission.

PREFACE

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

This document is one of 33 technical attachments to the final report of a larger research effort called *Integrated Energy Systems: Productivity and Building Science Program* (Program) as part of the PIER Program funded by the California Energy Commission (Commission) and managed by the New Buildings Institute.

As the name suggests, it is not individual building components, equipment, or materials that optimize energy efficiency. Instead, energy efficiency is improved through the integrated design, construction, and operation of building systems. The *Integrated Energy Systems: Productivity and Building Science Program* research addressed six areas:

- Productivity and Interior Environments
- Integrated Design of Large Commercial HVAC Systems
- Integrated Design of Small Commercial HVAC Systems
- Integrated Design of Commercial Building Ceiling Systems
- Integrated Design of Residential Ducting & Air Flow Systems
- Outdoor Lighting Baseline Assessment

The Program's final report (Commission publication #P500-03-082) and its attachments are intended to provide a complete record of the objectives, methods, findings and accomplishments of the *Integrated Energy Systems: Productivity and Building Science Program*. The final report and attachments are highly applicable to architects, designers, contractors, building owners and operators, manufacturers, researchers, and the energy efficiency community.

This attachment, "Integrated Ceiling Research Report" (Attachment A-28) provides supplemental information to the final report within the **Integrated Design of Commercial Building Ceiling Systems** research area. The "Integrated Ceiling Research Report" summarizes the research conducted to understand current building practices in skylit buildings with T-bar ceilings.

The Buildings Program Area within the Public Interest Energy Research (PIER) Program produced these documents as part of a multi-project programmatic contract (#400-99-413). The Buildings Program includes new and existing buildings in both the residential and the non-residential sectors. The program seeks to decrease building energy use through research that will develop or improve energy efficient technologies, strategies, tools, and building performance evaluation methods.

For other reports produced within this contract or to obtain more information on the PIER Program, please visit www.energy.ca.gov/pier/buildings or contact the Commission's Publications Unit at 916-654-5200. All reports, guidelines and attachments are also publicly available at www.newbuildings.org/pier.

ABSTRACT

The "Integrated Ceiling Research Report" was produced by the Integrated Design of Commercial Building Ceiling Systems project. This was one of six research projects within the *Integrated Energy Systems: Productivity and Building Science* Program, funded by the California Energy Commission's Public Interest Energy Research (PIER) Program.

The report is published as an attachment to the program's final report (Commission publication #P500-03-082), and as a supplement to the "Design Guidelines for Skylights with Suspended Ceilings," which were produced as part of this research project.

This report summarizes the research involved in understanding current building practices in skylit buildings with T-bar ceilings. It documents current construction details of skylights and suspended ceilings, as well as issues that arise when skylights need to be integrated with various building components. It also identifies the components needed to make skylight wells that bridge the gap between the underside of skylights and the T-bar ceiling. This research informed the primary final product of this project, the "Design Guidelines for Skylights with Suspended Ceilings." These Design Guidelines provide building designers with information on how to combine skylights and light wells with other building components in low-rise commercial buildings with T-bar ceilings.

Authors: Jon McHugh, Puja Manglani and Lisa Heschong, Heschong Mahone Group

Key words: daylighting, skylight, light well, T-bar ceiling, suspended ceiling, dropped ceiling, low-rise commercial building, commercial building ceiling, ceiling system, ceiling component

FINAL REPORT

Modular Skylight Well for Suspended Ceilings Research

by

Jon McHugh, Lisa Heschong,
Puja Manglani, Rocelyn Dee
Heschong Mahone Group

June 2003

Submitted to:
New Buildings Institute
Integrated Energy Systems
Productivity & Building Science Program
Contract Product Number Deliverable #5.4.2

On behalf of the
California Energy Commission
Public Interest Energy Research (PIER) Program
Contract Number 400-99-013

Integrated Design of T-bar Ceilings with Skylight Wells

Final Report for Task 5.4.2 Integrated Ceiling Research Report

June 2003
HMG Project #0015b

Submitted to:
Cathy Higgins, Senior Program Director
Integrated Energy Systems - Productivity & Building Science Program
A Project of the State of California PIER Program
New Buildings Institute, Inc.
P.O. Box 653
White Salmon, WA 98672
Tel: (509) 493-4468 Fax: (509) 493-4078

Submitted by:
HESCHONG MAHONE GROUP INC.
11626 Fair Oaks Blvd. #302
Fair Oaks, CA 95628
Phone:(916) 962-7001
Fax: (916) 962-0101
e-mail: info@h-m-g.com
website: www. h-m-g.com

ACKNOWLEDGEMENTS

The products and outcomes presented in this report are a result of funding provided by the California Energy Commission's Public Interest Energy Research (PIER) program on behalf of the citizens of California. Heschong Mahone Group would like to acknowledge the support and contributions of the individuals below:

Heschong Mahone Group, Inc.: Principal in Charge: Lisa Heschong. Project Director: Jon McHugh. Project staff: Puja Manglani and Rocelyn Dee.

Subcontractors: Jack A. Paddon and James L. Engler of Williams + Paddon Architects + Planners Inc., Marshall Hemphill of Hemphill Interior Technologies, and James Benya of Benya Lighting Design.

Review and Advisory Committee: We are greatly appreciative of the following people who contributed to the review of this report: William Beakes of Armstrong Industries, Jerry Blomberg of Sunoptics, Pete Guisasola of City of Rocklin Building Department, Rob Samish of Lionakis Beaumont Design Group, Michael White of Johnson Controls, Chuck McDonald of USG, John Lawton of Velux, John Mors of Daylite Company, Joel Loveland of Lighting Design Lab, Anthony Antonelli of Ecophon, Steve Fuller and Martin Powell of Albertsons, Jehad Rizkallah of Stop and Shop, Paul McConocha of Federated Departments, JimVan Dame of My-Lite Daylighting Systems and Products, Doug Gehring of Celotex, Ivan Johnson of TriStar Skylights, Robert Westfall of Solatube International Inc., Leo Johnson of PJHM Architects, George Loisos of Loisos/Ubbelohde Architects, Jim Kobs of Chicago Metallics, Steve Ritcher of Crystollite, Jackie Stevens of So-Luminaire, Peter Turnbull of PG & E, Sean Flanigan of WASCO Products, Richard Schoen of Southern California Roofing, Mike Toman and Jeff Guth of Ralphs and Food for Less, and Lori Johnson of Target.

Project Management: Cathy Higgins, New Buildings Institute; Don Aumann, California Energy Commission.

PREFACE

The HESCHONG MAHONE GROUP has produced this report as part of the Integrated Design of Commercial Building Ceiling Systems research element of the *Integrated Energy Systems - Productivity and Buildings Science* energy research program managed by the New Buildings Institute. Cathy Higgins is the Senior Program Director of this project for the New Buildings Institute.

The *Integrated Energy Systems - Productivity and Buildings Science* program is funded by the California Energy Commission under Public Interest Energy Research (PIER) contract No. 400-99-013. The PIER program is funded by California ratepayers through California's System Benefit Charges and is administered by the California Energy Commission (CEC). Donald J. Aumann is the CEC Programmatic Contact.

Foreword

This research in this report has been designed to support the Integrated Design of Commercial Building Ceiling Systems research element. This research project consists of three related components:

1. Effectiveness of lay-in insulation
2. Comprehensive skylight testing
3. Culminating in a modular skylight well protocol for suspended ceilings that provides quality lighting (including daylight) and energy savings.

This report describes the research into the building component integration issues needed to apply skylights to buildings with T-bar ceilings. This report is based on research into California building codes, interviews with building designers and building component manufacturers.

The purpose of this research element is to develop a protocol for designing and specifying highly efficient ceilings that will incorporate effective placement of insulation, daylighting via toplighting and daylight-responsive electric lighting controls. This protocol will help to reduce uncertainty regarding code compliance and construction costs.

ABSTRACT

This report forms a part of the integrated ceiling systems study and summarizes the research involved in understanding the issues that exist in current building practices in skylit buildings with T-bar ceilings. This report documents out the current construction details involved with skylights and ceilings and issues that arise due to integration of various building components. The aim of this report is to also identify the parts and components needed to make skylight wells that bridge the gap between the underside of skylights and the T-bar ceiling. This research will be used to develop two major products:

1. A modular skylight well protocol that describes the functional requirements of light wells used in conjunction with T-bar ceilings. Building component manufacturers can use this protocol to help guide development of modular skylight wells or component of light wells. Specifiers can also use this protocol to define the components and desired features of a light well.
2. An Integrated Ceiling Guideline for building designers on how to use the protocol and how to gracefully combine skylighting with other building components in low rise commercial buildings with T-bar ceilings.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The PIER modular skylight well project has as its goal the development of specifications and protocols that will simplify the process of specifying and constructing buildings that have both daylighting with skylights and acoustic tile "T-bar" ceilings. To accomplish this requires the understanding of the integration issues for all the building components that fit between the ceiling and the roof. This includes the T-bar ceiling, luminaires and their controls, mechanical ducts, plumbing, structural supports, roof decks, roofing, and skylights.

Problem statement

Currently, well-integrated skylighting designs that seamlessly meld the building structure, ceiling system, electric lighting, photocontrols, HVAC ductwork and skylights are custom designs. Such designs require a substantial amount of research by the designer. The installed costs of such systems are uncertain because the contractor has to make costly revisions to make the components fit together. This can limit the application of this type of highly efficient, high quality ceiling system to a highly motivated building owner and a diligent designer.

Well-defined requirements are a direct signal of the design constraints to manufacturers that wish to enter the market. As a result, the market accepts only higher quality components, which interface well with the other components.

Construction quality is improved when components are designed to fit together rather than having to “jury-rig” an ad hoc solution.

Skylights are often not considered for T-bar ceilings and T-bar ceilings are often removed from design for Skylit Buildings. Lack of communication between various building component manufacturers and designers limits the application of highly efficient, high quality ceiling system

Project Goals

The main goals of the project are to develop non-proprietary protocol and a design guideline for advanced ceiling systems that:

- Provides excellent lighting and daylighting quality, thermal comfort, lower construction costs, acoustic performance, and energy efficiency
- Allows modularity and interchangeability of components so that multiple sourcing can be assured for competitive pricing, fast track availability, and eventual replacement of components and reconfiguration.
- Addresses multi-dimensional requirements of flammability, seismic safety, acoustics, thermal and solar heat gain transmittance, and glare and data communication

- Assures that the ceiling system meets overlapping safety, energy and environmental quality requirements
- Allows design freedom but address building codes and component integration issues.

This document forms a part of the modular light well systems project and forms the basis for formulating the design protocol and the design guidelines.

Why Skylights and T-bar Ceilings?

Skylights are desirable for commercial buildings as they save energy, improve productivity and enhance lighting quality. T-bar ceilings at present are widely used in commercial buildings and are best suited for acoustics, aesthetics, and flexibility. A sizable fraction of the commercial building stock changes ownership or tenancy frequently. Thus one of the desirable features of dropped ceilings is that they are easily re-configurable to accommodate changes in lighting, HVAC, added partitions and new tiles.

Selection of Targeted Occupancies

This focus of this research is on low-rise commercial buildings like offices, retail stores, grocery stores and schools in California. These building types are spaces that traditionally use T-bar ceilings in their spaces. As shown in Figure 1, offices, grocery and retail stores comprise 46% of the total new construction non-residential building area in California. Schools, which are owner occupied spaces, are willing to invest in productive environments.

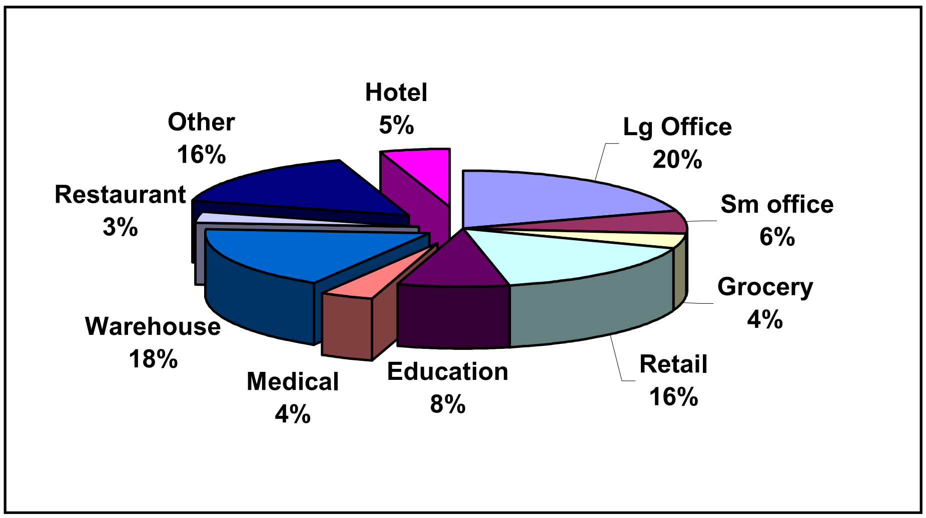


Figure 1: Distribution of California New Construction Floor Area by Occupancy[1]

[1] Brook, M. 2002. "California Electricity Outlook: Commercial Building Systems". Presentation at PIER Buildings Program HVAC Diagnostics Meeting, Oakland, CA. April 16. Small office buildings are defined as having floor area under 30,000 SF.

Recent reports on the value of daylighting as correlated to higher test scores in schools[2] and increased retail sales[3] have increased interest in daylighting by both these owner groups. Skylighting has become almost synonymous with big box retail. Several grocery store chains are using skylighting regularly or are experimenting with skylighting.

Retail has the option of eliminating ceilings when adding skylights - the cost savings of eliminating the ceilings has to be weighed against the cost of all metal ductwork and the aesthetic look one is trying to achieve. Open ceilings can give the impression of a "cost-cutting" low margin store. Also retailers are trying to respond to the low cost of Wal-Mart stores which use skylighting and have eliminated T-bar ceilings. Much of the retail sector will still value acoustic ceilings for aesthetics, sound control and flexibility afforded by T-bar ceilings even in buildings with skylights.

Figure 2: Interior of Daylit Wal-Mart Store

Schools and offices typically need acoustic tile ceilings even when skylights are part of the design. As described by several articles in the February 2003 ASHRAE Journal, ANSI Standard 12.60-2002[4] sets several stringent background noise requirements for schools that will be hard to meet without the use of acoustic ceilings and remote air conditioning systems. Many of these same background noise issues apply to offices as well.

---

[2] Heschong Mahone Group, (HMG) 1999, *Daylighting in Schools: An Investigation into the Relationship between Daylighting and Human Performance*, Pacific Gas & Electric, 1999

[3] Heschong Mahone Group, (HMG) 1999, *Skylighting and Retail Sales*, Pacific Gas & Electric, 1999.

[4] ANSI Standard 12.60-2002, *Acoustical Performance Criteria, Design Requirements and Guidelines for Schools*, American National Standards Institute.

Targeted ceiling and plenum heights

This projects focuses on certain ceiling and plenum heights. The targeted ceiling heights for low-rise commercial buildings considered in this project are from 9 feet to 15 feet. The targeted plenum heights for the purpose of this study are from 4 feet to 12 feet. Detailed description of spacing issues has been discussed in section “Spacing Issues in Construction “ of this report.

Market and Energy Impacts

Approximately 75% of new commercial construction (excluding warehouses) makes use of dropped ceiling systems (T-bar and acoustical tile). Acoustic ceiling/lighting design affects fire protection, seismic safety, lighting, daylighting, insulation, mechanical systems and acoustics. Electric lighting accounts for over one third of all commercial electricity consumption, and over one quarter of peak demand for commercial buildings and 11% of peak demand for all uses in California. As shown in Table 1, over 65% of ceiling area is directly below a roof and therefore, there is a significant amount of building area that could be daylit with skylights.[5]

Floors	Total Area (in Million sq ft/yr)	Fraction of All Building Stock	Area Under Roofs (in Million sq ft/yr)	Fraction Under Roofs
One	563	51%	563	51%
Two	266	24%	133	12%
Three	97	9%	32	3%
4 to 9	132	12%	22	2%
> 9	51	5%	3	0%
Total	1,109	100%	754	**68%**

Table 1: U.S. Annual Commercial Buildings Construction Area Segmented by Number of Stories and Fraction of Total Area Under a Roof

The area that can be toplit with skylights, is about one and a half times the floor area that can be reasonably sidelit. By reasonably sidelit, we use the traditional definition of the daylit zone being within 15 feet of the perimeter wall.[6] Table 2 steps through the calculation procedure of the potential sidelit area and shows that about 47% of floor area in the US existing commercial building stock is within

[5] Table B9. *Year Constructed, Floorspace, 1999.* from Buildings Energy Consumption Survey (CBECS), US Energy Information Administration. http://www.eia.doe.gov/emeu/cbecs Data is for an average year's new construction for the 10 year time period ending in 1999.

[6] This 15 foot perimeter distance is also the basis of the definition of the *daylit area by vertical glazing* in the Title 24 building efficiency standards.

15 feet of the perimeter walls. Note the much larger total area for this analysis as compared to that of area under a roof in new construction. This cross-tabulation of building height and area is for all existing building stock in the U.S.

The data in gray is the original source data from Table B7 of the CBECS database. The calculations err on the side of more daylit zone by assuming that the aspect of length to width is 2:1. If the width of the building is less than 30 feet, then the entire floor area is presumed to be within the daylit zone. Otherwise, the daylit zone is 2 x 15 x width + 2 x 15 x (length - 30) , where length is width x 2.

Table B7. Building Size, Floorspace, 1999									
	Total Floorspace (million square feet)								
	Building Size								
	1,001 to 5,000 Square Feet	5,001 to 10,000 Square Feet	10,001 to 25,000 Square Feet	25,001 to 50,000 Square Feet	50,001 to 100,000 Square Feet	100,001 to 200,000 Square Feet	200,001 to 500,000 Square Feet	Over 500,000 Square Feet	Totals
Average Size	2,500	7,500	15,000	35,000	60,000	125,000	300,000	750,000	
Floors									**Totals**
One..................................	4,898	4,726	4,887	3,929	3,377	2,930	1,328	724	26,799
Two..................................	1,528	2,263	3,689	2,922	2,799	1,645	1,059	1,081	16,986
Three	278	942	1,907	1,475	1,776	1,128	942	Q	8,448
Four to Nine	Q	308	666	979	2,015	2,112	2,325	1,704	10,109
Ten or More	N	N	Q	Q	Q	457	1,197	2,638	4,292
Totals...............................	*6,704*	*8,239*	*11,149*	*9,305*	*9,967*	*8,272*	*6,851*	*6,147*	*66,634*
Avg area per floor									# Floors
One..................................	2,500	7,500	15,000	35,000	60,000	125,000	300,000	750,000	1
Two..................................	1,250	3,750	7,500	17,500	30,000	62,500	150,000	375,000	2
Three	833	2,500	5,000	11,667	20,000	41,667	100,000	250,000	3
Four to Nine	417	1,250	2,500	5,833	10,000	20,833	50,000	125,000	6
Ten or More	167	500	1,000	2,333	4,000	8,333	20,000	50,000	15
Building Width 2:1 aspect ratio									
One..................................	35	61	87	132	173	250	387	612	
Two..................................	25	43	61	94	122	177	274	433	
Three	20	35	50	76	100	144	224	354	
Four to Nine	14	25	35	54	71	102	158	250	
Ten or More	9	16	22	34	45	65	100	158	
15 ft perimeter zone									
One..................................	91%	61%	46%	31%	24%	17%	11%	7%	
Two..................................	100%	80%	61%	43%	34%	24%	16%	10%	
Three	100%	91%	72%	51%	41%	29%	19%	12%	
Four to Nine	100%	100%	91%	68%	55%	40%	27%	17%	
Ten or More	100%	100%	100%	93%	78%	59%	41%	27%	
Total Area in Sidelit Zone									**Totals**
One..................................	4,470.9	2,905.8	2,246.1	1,235.5	826.7	506.3	150.3	52.3	12,393.9
Two..................................	1,528.0	1,808.7	2,268.2	1,255.4	944.4	395.1	167.7	109.7	8,477.2
Three	278.0	859.9	1,373.0	755.3	719.3	327.3	181.1	Q	4,493.8
Four to Nine	Q	308.0	607.9	664.7	1,101.0	840.0	619.9	294.5	4,435.9
Ten or More	N	N	Q	Q	Q	269.2	484.8	703.3	1,457.3
Totals	*6,276.9*	*5,882.3*	*6,495.3*	*3,910.9*	*3,591.4*	*2,337.9*	*1,603.7*	*1,159.8*	*31,258.1*
Percent of total	**94%**	**71%**	**58%**	**42%**	**36%**	**28%**	**23%**	**19%**	**47%**

Table 2: Estimate of Building Area within the Perimeter Daylit Zone

Daylighting Potential

Table 3 illustrates the potential energy cost savings from installing skylights in the five targeted building types described above in the section "Selection of Targeted Occupancies," and consider only the fraction of spaces that are directly under a roof, have T-bar ceilings and where adding skylights are feasible. This table shows that one year's worth of new and retrofit construction would save California ratepayers approximately $3.2 Million, or after 10 years the ratepayers would be saving $32 Million per year!

Occupancy	New or Retrofit M SF/yr	Under Roof	T-bar Ceiling	Feasible	Total Million SF/yr	$/SF-yr	Annual Savings ($Millions)
Lg Office	30.9	35%	45%	50%	2.4	$ 0.15	$ 0.4
Sm office	9.9	50%	45%	50%	1.1	$ 0.15	$ 0.2
Grocery	6.6	100%	46%	75%	2.3	$ 0.23	$ 0.5
Retail	24.8	80%	46%	75%	6.9	$ 0.23	$ 1.6
Education	12.6	60%	68%	75%	3.9	$ 0.16	$ 0.6
Totals	**84.8**				**16.5**		**$ 3.2**

Table 3: Feasible Energy Cost Savings Potential from One Year's New/Retrofit Construction for 5 Selected Building Types

This estimate assumes that on average large office buildings are 3 stories tall, small offices are two story, all grocery are one story as are most retail and that schools are primarily one story with some two and three story construction. The estimate of T-bar ceilings comes from an internal Armstrong World Industries market survey of managers of existing commercial buildings. The results were segmented into Office, Retail and Educational. This estimate is conservative since we expect that grocery actually has more suspended ceilings than the rest of retail.

Offices have the lowest feasibility due to three factors: sufficient daylight from windows, areas covered by mechanical rooms or other rooftop equipment, and utility areas that are infrequently occupied.

The cost savings analysis was based upon an electric energy cost of $0.115/kWh and a natural gas cost of $0.611/therm. Energy savings estimates were calculated using the SkyCalc, skylight design calculation spreadsheet.[7] The prototypical buildings in SkyCalc all had double glazed medium white skylights over a 5 foot deep diffusing white light well. The electric lighting power density of retail and grocery spaces was 1.6 W/SF; classrooms and offices had a 1.2 W/SF lighting power density.

If the increases in natural gas consumption are converted into kWh of energy and combined with the kWh of electricity savings the net energy savings for the state of California would be 16 Million kWh/yr for each years construction. After the

[7] L. Heschong and J. McHugh. "Skylights: Calculating Illumination Levels and Energy Impacts," Journal of the Illumination Engineering Society, Winter 2000, Vol. 29, No. 1, pp. 90-100

10th year of adding skylighting to all feasible commercial spaces with suspended ceilings this would amount to 160 Million kWh/yr of net energy savings.

Research Methodology

This section describes the various steps taken in researching the current practices and issues involving in integration of roof, T-bar ceilings and skylights with other building systems. The research is based on the following methods:

Existing Literature Review

The existing literature was collected from the following sources:

- Manufacturers' product manuals.
- Internet sites on building construction.
- Project subcontractors: Jack Paddon, Architect; James Benya, lighting designer; and Marshall Hemphill, Hemphill Interior Technologies.
- Fire and seismic codes

Phone Interview with Architects/Contractors

Phone interviews were carried out with architects in California and elsewhere who have had prior experience with designing skylights. The phone interviews were focused on issues that had to be address by them when designing buildings with skylights and T-bar ceilings and their suggestions and ideas on the design of the light well.

Steering Committee

A steering committee was selected from the project technical advisory group to help chart the direction this project should take. The steering committee was included the project sub contractors and one or two representatives from manufactures of acoustic tile, T-bar, and skylights. Also invited was a daylighting consultant from the Seattle Daylighting Lab.

A detailed record of the steering committee meeting is available in the PIER Integrated Ceilings document, *Steering Committee Meeting Summary* dated February 26, 2003.

Case Studies

Twenty low-rise commercial buildings with skylights and T-bar ceilings were studied for their construction details. These case studies were based on site visits, plan reviews and interview with their architects. The purpose of these case studies was to learn from the experience of others who have installed skylight wells in T-bar ceilings.

BUILDING CODES RESEARCH

When a building design incorporates both skylights and T-bar ceilings, it has several repercussions to the rest of the building design. From discussions with our technical advisory group, the primary code constraint encountered when poking a hole through the ceiling plane and the roof are fire code and seismic constraints. Given below is a summary of the research involving the fire and seismic codes based on the California code requirements.

Fire Code Requirements

Fire code compliance is based on occupancy of a building and the types of materials used in the building construction. The fire rating of materials and assemblies, requirements of sprinkler and other fire extinguishing systems (described in the next section) when skylight wells and T-bar ceilings are used, all depend on the occupancy type and building material classification described below.

The occupancy types that are part of this research study are:

Group A (Assembly): Includes the use of a building of 50 or more persons for civic, social, religious, recreation, education or instruction

Group B (Business): Includes offices, professional or service type transactions

Group E (Education): Any building used for educational purposes through 12th grade for more than 12 hours per week or four hours in one day

Group M (Mercantile): Includes buildings used for display and sale of merchandise and involving stocks of goods, wares or merchandise accessible to the public.

Sprinklers

Skylight wells may or may not need a sprinkler head, and this depends upon the judgement of the local code official. The policy of the jurisdiction should be queried early on to inform the sprinkler system design or one can design to the worst case and install a sprinkler in each well.

Sprinkler requirements are per California Building Code[8], California Fire Code[9] 1003 & Uniform Fire Code[10] Article 10 & 81. Sprinklers can be used in lieu of the one-hour requirement for some building types. Sprinklers can also be used in “B” (business) occupancies to waive the requirement for one-hour corridors if the

---

[8] California Building Code, 2001, Chapter 9

[9] California Fire Code, 2001, Article 10, Section 1003

[10] Uniform Building Code, Article 10 and 81

total occupant load is below100 people. Adding sprinklers can also be used to increase the travel distance to exits (especially in commercial occupancies like retail stores.

Location and Spacing[11]: Sprinklers are required by code for attic spaces below roof deck. They are typically spaced at 10' x 12' for wood construction and 10' x 12' or 8' x 15' for steel construction. In office buildings, sprinklers are typically required for every 10' x 12' of area and if the pressure of water supply is good and sprinkler heads are changed out to extended coverage heads, then the spacing can be at 16' x 16'.

Requirements for fire extinguishing systems based on occupancies as given in the California Building Code are:

- An automatic sprinkler shall be installed in every story or basement when floor area exceeds 1,500 SF. Openings shall have a minimum dimension of not less than 30 inches.
- In group A occupancy, a sprinkler system shall be installed in basements larger than 1,500 SF, other building spaces more than 12,000 SF used for exhibition or display purposes.
- In group E occupancy, an automatic sprinkler is required in basements and in stair that have enclosed spaces below or over stairways.
- In group M occupancies, an automatic sprinkler system shall be installed in rooms where floor area exceeds 12,000 SF on any floor or 24,000 SF on all floors or more than three stories in height.

Smoke Vents

Smoke vents are, at times, used in combination with skylights in some buildings. If a fire breaks out in the plenum space, the light well can be a barrier to smoke venting. There is an ongoing disagreement if smoke venting is a good thing when combined with sprinklers - the smoke vents may keep the space temperatures low enough that the sprinklers don't turn on. This project does not deal with the issues regarding smoke vents. However, here is a brief description of the smoke vent requirements based on the codes:

Smoke and heat removal codes (type of vents, vent location and dimensions) are in accordance with California Fire Code8102.7. Vents are required based on the size of high-pile storage within a building of class I-IV and high hazard material storage. Smoke vents are available that are approved by Factory Mutual Test Standard 4430 and UL standard 793[12]. Smoke vents do not carry a fire rating.

---

[11] National Fire Protection Agency, NFPA Handbook Edition Eight

[12] Underwriters Laboratory 793-Standard for Safety for Automatically Operated Roof Vents for Smoke and Heat

Fire Rating of Buildings

Fire ratings of buildings is an important part to be considered while designing skylight wells. Most of the materials used for skylight well and ceiling, have fire ratings that meet with the code requirement. These ratings are based on ASTM standards, and compliance is determined by several independent, non-governmental testing services such as Underwriters Laboratories.

The industry evaluates life-safety compliance with two ratings:

- Flame spread/smoke developed of materials
- Fire resistance of assemblies

Class Ratings of materials

The first is the Fire Class/Surface Burning Characteristics as defined by ASTM-E1264[13]. 'Class A' for building interior finishes (the best rating possible) means that products do not exceed a flame spread rating of 25 and do not continue to combust after the test flame has been extinguished. Also, they do not exceed a smoke developed rating of 50. A flame spread rating relates to the relative rate at which flame will spread over the surface of the material. The required standard for most commercial applications is a flame spread rating of 25 or less (for Class A ceilings). Table number 8-A in California Building Code describes the flame spread classification for interior finishes.

Class A, B, C are also used for roof coverings and defines the rating for roofing membranes typical in accordance with UL classifications and primarily tested in accordance with ANSI/UL 790 which is similar and meets all criteria of ASTM E-108[14]. These measure the flame spread on the exterior surface of the roof assembly. Factory Mutual (FM) also classifies roofs with A, B, C and their testing is in accordance with ASTM E-108. Hourly ratings are listed in UL 263 [15] which is similar to ASTM E-119[16]. Table number 15-A in California Building Code describes the ratings for roofs.

Fire Rated Ceiling Assemblies

The fire-resistance rating relates to the ability of an assembly to prevent the spread of fire between spaces while retaining structural integrity.

Ceilings are tested by Underwriters Laboratories, for their resistance to the spread of fires within buildings. These are hourly designations and measure the ceiling's ability to protect occupants, fire fighters, and the building structure. The most common rating is the one-hour rating, but ratings go up to three hours.

---

[13] ASTM-E1264-98- Standard Classification for Acoustical Ceiling Products, American Society for Testing and Materials

[14] ASTM E-108-Standard Test Methods for Fire Tests of Roof Coverings

[15] Underwriters laboratory 263- Fire Tests of Building Construction and Materials (a.k.a. ASTM E119, NFPA 251, and UBC 7-1).

[16] ASTM E119-00a Standard Test Methods for Fire Tests of Building Construction and Materials

These tests incorporate complete assemblies involving ceiling/floor designs and ceiling/roof designs. Fire-resistance ratings apply only to a floor/ceiling or roof/ceiling assembly in its entirety. Individual components such as ceiling panels or suspended grid are not assigned separate fire resistance ratings.

UL fire-resistance ratings are applied to certain types of floor/ceiling and roof/ceiling construction assemblies. Each is tested to endure fire exposure for a given time period in compliance with UL test conditions (Standard-ANSI/UL 263). The resulting ratings are measured in hours and published in the UL Fire Resistance Directory. Table number 7-C of California Building Code gives a list of fire resistance rating for floor-ceiling assemblies.

Based on the discussions with the technical advisory group for this project, it was concluded that rating a whole ceiling assembly, rather than its components, is not particularly desirable because it limits the flexibility of the ceiling and any change has to also be rated. It is also quite expensive to get a UL rating on one's ceiling assembly. Rated assembly might be appropriate for out-of-the-box assemblies. There are usually different ratings for insurance and for building codes. Most of the spaces that have been talked about are sprinklered and thus ratings are only an issue for fire exit corridors.

Fire Rating of Skylights

The CBC[17] specifies the allowable skylight glazing and framing. In Type I and II construction, skylight frames must be constructed out of noncombustible materials.

Seismic Code Requirements

Addition of a skylight in the roof involves disruption of the roof seismic diaphragm by the openings for the skylights. The solution is often to increase the strength of the diaphragm connections via extra nailing, screwing or welding. The cost of this is generally trivial compared to other issues. The primary impact is asking the structural engineer to do another calculation. If skylights curbs and throats are properly braced back to roof, they are not likely to be a problem. In current practices for skylights, the extra bracing is provided at the throat and the splay

Seismic requirements, according to the California Building Code relate to the installation and performance of grid systems with regard to grid strength. ASTM E580[18] and the Uniform Building Code UBC-25-2 are applicable common standards. The testing and standards relate to the compression and tension strength of grid connections. There are no seismic ratings or requirements for ceiling panels. For figures, refer to Appendix A.

[17] California Building Code,2001,Section 2409

[18] ASTM (American Society for Testing and Materials)- E580-02 Standard Practice for Application of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Requiring Moderate Seismic Restraint

Seismic Requirements for Metal Suspension System

According to the California Building Code, section 2501A.5[19]:

- Bracing assemblies are required to be spaced at not more than 12'x12' on center for school assemblies. For essential services buildings, bracing assemblies are to be spaced not more than 8'x12' on center.
- At the edge of vertical ceiling offsets and perimeter walls, bracing assemblies need to be at locations not more than half the spacing given above. The splay of these wires shall not exceed 45 degrees from the plane of the ceiling.
- Suspended acoustical ceiling systems with a ceiling area off 144 SF or less and fire rated suspended acoustical ceiling systems with ceiling area of 95 SF or less, surrounded by walls which connect directly to the structure above, do not require bracing assemblies when attached to two adjacent walls.
- Metal panels and panels weighing more than one half (0.5) pound per square foot, other than acoustical tile, are to be positively attached to the ceiling suspension runners.
- When gypsum board or other ceiling finishes are attached to the framing, special details are required for the vertical hanger wire and lateral bracing wire support connections to the framing.

Refer to Appendix A for metal suspension grid seismic requirements as per California Building code.

Energy Code (Title 24)

The following description of California Building Energy Efficiency Standards (Title 24) as they relate to T-bar ceilings is based upon the standards language proposed for 2005[20]. Section 118(e) of the proposed standard would, in most cases, give no credit for "lay-in" insulation placed on top of acoustic ceiling tiles. Only in small areas (under 2,000 SF) with over 12 foot tall plenum heights would the insulating value of lay-in insulation be credited towards meeting the insulation needs of the building envelope. Thus all of the designs considered here will assume that insulation is applied to either the topside or underside of the roof deck.

Since the base assumption is that the insulation is at the roof deck, all the area under the roof deck will be in conditioned space. Thus there will be no requirement for insulating the side of the light well.

The "daylit area" under skylights is proposed as the "the footprint of the skylight plus, in each of the lateral and longitudinal dimensions of the skylight, the lesser

[19] Interpretation of Regulations Document, California Department of General Services, Division of the State Architect, based on California Building Code, Section 2501A.5

[20] 2005 Building Energy Efficiency Standards for Residential and Nonresidential Buildings, Draft 3, February 2003, P400-03-001D3.

of 70% of the floor-to-ceiling height, the distance to the nearest 60-inch or higher opaque partition…" As shown in Figure 3, the net effect of this definition is that the daylit area under skylights is found by expanding the opening at the bottom of the light well by 35° in all directions to the floor.

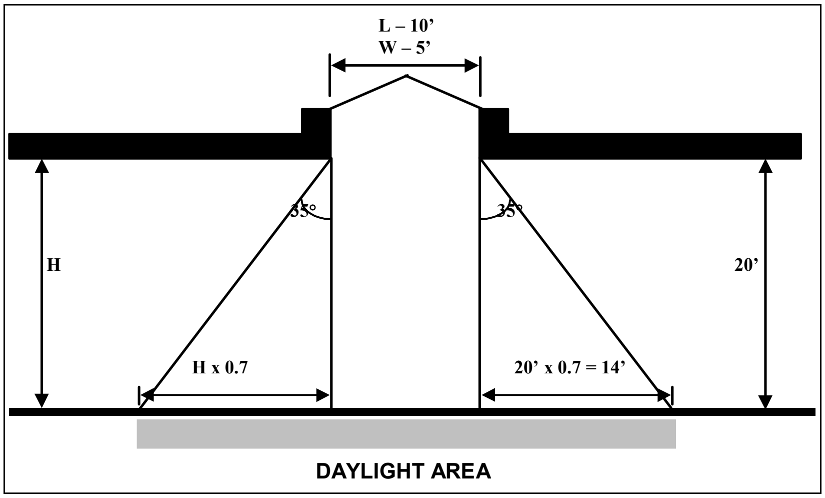


Figure 3: Revised Illustration of the Skylight Daylit Area

When the daylit area under skylights exceeds 2,500 SF, Section 131(c) of the proposed standards would require an astronomical timeclock or a photocontrol system to turn off interior lighting in the daylit zone. The purpose of this requirement is to reduce electric lighting energy consumption when there is sufficient daylight.

The most notable impact on skylighting is proposed for Section 143(c) of the building energy efficiency standards. This section would establish skylights as the base case or prescriptively require them for low rise nonresidential buildings that have spaces larger than 25,000 SF directly under a roof and the ceiling height is greater than 15 feet. At least half of the space is required to be daylit. For spaces with less than 1 W/SF lighting power density, the required skylight to floor area ratio (SFR) must be at least 3% and for spaces with greater than 1 W/SF lighting power the SFR must be at least 3.6%.

Title 24 in Section 143(a)6, places prescriptive upper limit on skylight area of 5% for all buildings excepting atria greater than 55 feet tall. An alternative to the prescriptive requirements is to perform a computer simulation that shows that your design consumes less energy than the prescriptive "reference case" building.

Evaluation of Light Well Materials

A list of materials potentially used in light well construction has been compiled and the properties of these materials are tabulated in Table 4. The various indexes in this table are defined as follows:

- “Flame spread” describes how quickly the material burns and spreads the fire. Flame spread should be compared to the maximum flame spread of 25 allowed for Class A building products.
- “Smoke developed” describes the amount of smoke formed when a material burns. The values in this table should be compared to the maximum smoke developed rating allowed for Class A building products (less than 50).
- Weight - given in pounds per square foot of the thickness of the material described. Greater weight of a product increases the forces that are developed on the light well during an earthquake and increases the amount of bracing required to keep the well supported.
- Thermal resistance - in units of hr·°F·ft^2/Btu. Higher number indicates that less heat will be able to flow through the side of the light well. Except for light wells installed in ceilings with lay-in insulation, there is no code requirement to insulate the light well.
- Material Cost - $/SF. This indicates the typical material cost associated with each material. This material cost could be offset if a particular material substantially reduces labor costs, or is lightweight and does not require as much bracing.

Table 4: Application Matrix of Light Well Materials

Material	*Smoke Developed*	*Flame Spread*	*Weight* lb/SF	*R-value* °F·SF/Btuh	*Material Cost* $/SF
Drywall 5/8"	< 50	< 25	2.6	0.56	0.18 - 0.20
Mineral fiberboard acoustical tiles 5/8"	< 50	< 25	1.0 - 1.4	1.5 - 1.6	0.35 - 0.40
Mineral fiberboard acoustical tiles 5/8"	<50	< 25	0.6 - 1.4	1.5 - 1.7	0.24 - 0.28
Polystyrene Polyisocyanurate	165 50 - 215	25 25	0.15 - 0.3 0.12 - 0.2	5.00 5.5 - 6.3	0.39 0.33
Fiberglass duct board 1" thick	< 50	<25	0.25	4.3	0.70 - 1.27
foil/ fiberglass-polyester blend fabric	5	5	0.032	0	1.50
Plywood					
Sheet metal 22 ga ductwork	0	0	1.25	0	0.32

The nominal flame spread values can be misleading as described in an example of UL certification report for a rigid insulation product. The nominal values reported included a 'flame spread' of 5 and a 'smoke developed' 115 for the product itself but these values were followed with asterisks that included the following caveat:

** Flame spread and smoke developed recorded while material remained in original test position. Ignition of molten residue on the furnace floor resulted from flame travel equivalent to calculated flame spread classification of 45 and smoke developed classification of 350.[21]

The smoke developed index describes the quantity and opacity of the smoke generated by burning various materials and is what is required for complying with the building codes. However it is prudent in material selection to consider toxicity of the smoke generated by combustion. The Expanded Polystyrene Association of South Africa found the following relative toxicities of gas burning rigid insulation products. "From the Naval Engineering Standard, NES 713, a method that calculates a toxicity index based on 14 quantitatively determined combustion and/or thermal decomposition gases, we see a toxicity index for expanded polystyrene of 1.8, and 40 and 45 respectively for polyisocyanurate and polyurethane."[22]

[21] This is reported in Technical Bulletin 103 of Polyisocyanurate Insulation Manufacturers Association (PIMA) on the Internet at: http://www.pima.org/tbull103.html

[22] "The whole truth about expanded polystyrene, Expanded Polystyrene Association of South Africa (EPSASA)" http://www.epsasa.co.za/documents/truth_about_ep.doc

CONSTRUCTION PRACTICE RESEARCH

This section of the report summarizes the current construction practices being used in low-rise commercial buildings in the state of California. Sources for most of the information summarized below has been interviews with the local architects and building manufacturers and product catalogs.

Roofing

Roof Types

The two main types of roof construction commonly seen in low-rise commercial buildings in California are metal deck and wood deck construction. Low-rise construction commonly has panelized wood roof systems or metal decking over steel structure. The use of concrete over metal decking is not too common in this type of construction. Tilt-up concrete for wall construction works well with wood roof structures and metal roof structures. Since both are commonly used, our protocol will address both roof types.

Roofing Membranes

Built-up bitumen roofing is commonly used over wood decks, with batt insulation in the attic space below the roof structure. Built-up systems are typically a four or five-ply system with a cap sheet forming the last ply (layer). For roofs made of metal deck, commonly single Ply PVC, TPO and EPDM are applied over rigid insulation over the metal decking. Single ply roofing materials over a metal deck can prove to be as cost effective as built up roofing membranes.

Insulation

Typically, insulation can be placed in three locations: above roof deck, under roof deck or lay-in insulation on T-bar ceilings. Revisions to the proposed 2005 Title 24 energy code would effectively prohibit lay-in insulation. The energy code requires either R-11 insulation in the mild coastal zones (CA climate zones 6 through 9) and R-19 insulation in all other climate zones.

Metal roof decks are almost always insulated with rigid insulation placed on top of the deck. The insulation provides a smooth substrate for the roofing material. The rigid insulation (often polyisocyanurate, but also polystyrene or polyurethane) is mechanically fastened with screws.

In wood deck roof construction, fiberglass batt insulation is typically installed below plywood decking between the roof framing members with a wire tie system, mesh or stapling. When insulation is not covered by a finish material, as is usually the case in a plenum, the fiberglass batts maynot be covered with a flammable materials such as kraft paper. Instead the batts are usually foil faced.

Ceiling Panels, T-bar Grids and Connectors

Typically, acoustical tile ceilings in low-rise commercial buildings are 2' x 4' or 2' x 2' grid. The ceiling tile grid is generally independent of the structural layout above. Other available sizes of ceiling panels are 2' x 8' and 4' x 4'. The ceiling panels are typically made of fiber glass, and mineral fiber.

The T-bar suspension grid is typically made of galvanized steel, extruded aluminum and rolled steel. The T-bar suspension grid also comes along with various accessories and parts that give the flexibility to connect to any kind of ceiling panel designs, skylight wells and electric lighting fixtures. There are numerous types of edge details between the T-bars and the ceiling panels. Appendix B gives a description of some of the ceiling panels and suspension grid products available in the US market.

T-bar suspension grids typically come in 15/16" or 9/16" grid width. The 15/16" grid has been a standard grid dimension since approx. 30 years, as this dimension gives enough space to hold ceiling panels and takes care of the tolerance due to expansion of the material. Recently, the narrower dimension of 9/16" has also become common, as an option for designers who want to have a less exposed grid system. The main parts of a grid are:

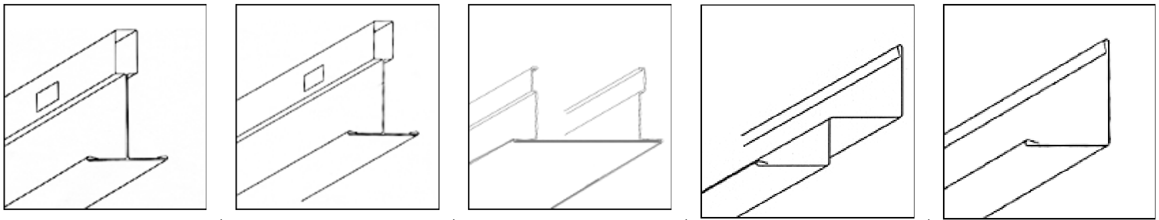
Main Runner: These are the framing members that run full length or width of the room and are the primary support for the ceiling weight. They are hung by hanger wire from joists or other supports above.

Cross Tee: This piece snaps into the main tees at right angles and serves as secondary support members for ceiling panels.

Wall Angle: This is an L-shaped metal strip that provides continuous finished edge around the perimeter of the ceiling where it meets a wall.

Hanger Wire: This is typically a 12-gauge wire, specified by most local building codes to support the ceiling grid.

Compression posts are used for extra seismic support to restrict vertical movement and splayed wires, where required by code, are used to restrict lateral movement. Figure 4 shows the various parts of the suspension grid system. Figure 5 shows three typical grid options with suspension system and the ceiling panels. Figure 6 shows one example of a metal suspension grid system.



Main runner	Main runner	Cross tee	Wall Angle	Wall Angle

Figure 4: Parts of a suspension grid system

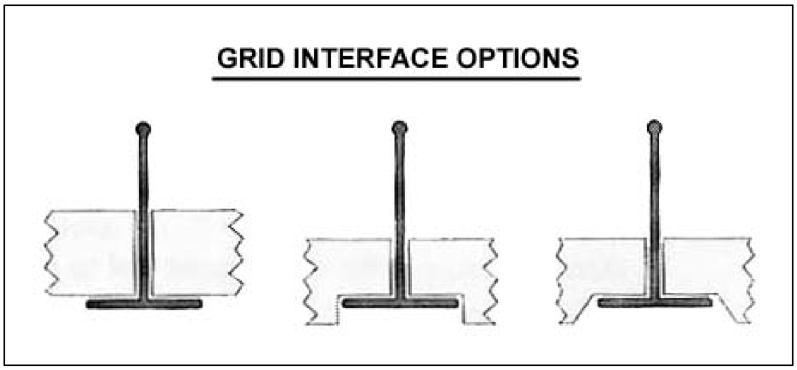


Figure 5: Typical Grid interface options with ceiling panels

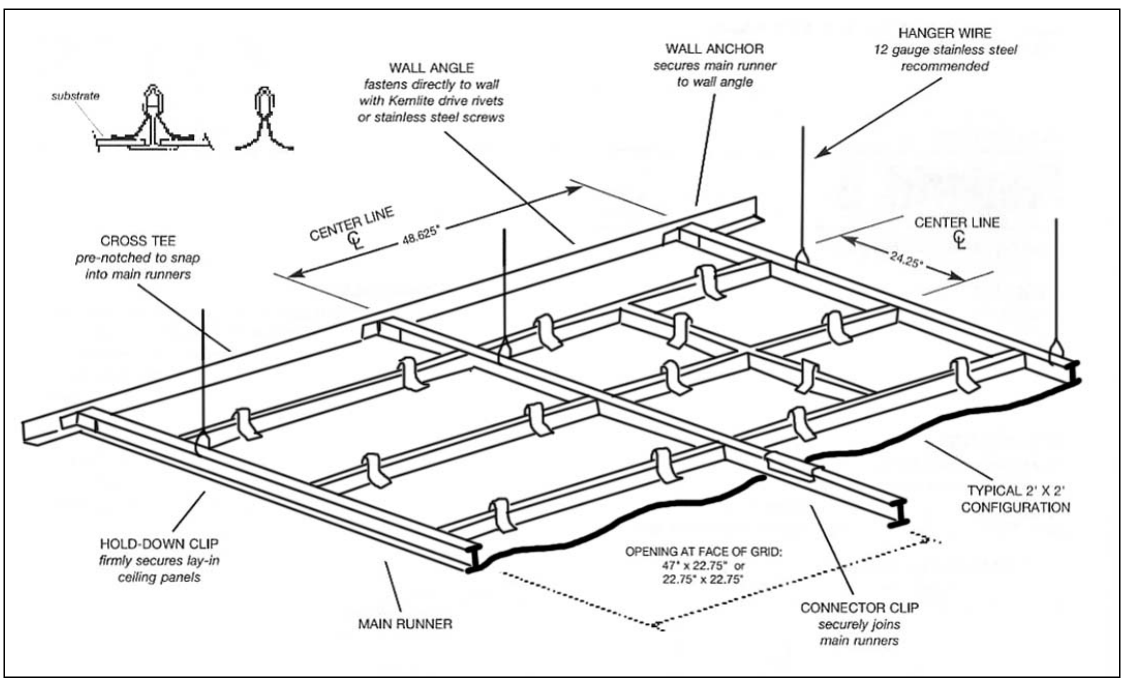


Figure 6: One example of a metal suspension grid system

Electric Lighting

Electric lighting luminaires in T-bar ceiling applications for low-rise commercial buildings are recessed 2' x 4' or 2' x 2' fluorescent troffers and suspended pendant fixtures. Lighting layout for recessed fixtures is affected directly by acoustic tiles layout. Lighting layout for suspended fixtures is marginally affected by acoustic tiles grid layout.

HVAC

In mechanical systems, diffuser types vary, but are typically designed to install into acoustical tile grid systems. The standard sizes of ceiling panels determine the sizes of register/diffuser for symmetrical appearances. Some design considerations also have to be made in buildings that have skylight wells. For cooling purposes, cool air is generally introduced at higher velocities and when placed too close to the edge of the light well, will limit the travel distance of the air. It is up to the mechanical engineering design to accommodate linear diffusers or square diffusers as long the equipment can handle efficient cooling or heating.

Skylight and Curb

Skylights are commonly made in sizes that increase in 1 foot increments. The most common commercial and industrial sizes are: 4' x 8' (size of a sheet of plywood), 5' x 6' (often joist spacing under steel decking is 5 feet on center), 5' x 4' and 4' x 4'.

Skylights are attached to the roof by means of a curb which raises it above the roof surface. Curbs are usually site fabricated out of wood. Prefabricated steel curbs are also frequently used, especially with steel decks where they can be welded to the deck.

The skylight is installed on top of the curb and is typically fastened to the curb with screws. Glazing tape or mastic is applied to the top of the curb before the skylight is attached to provide a waterproof seal.

The curb is attached to the roof with screws, or in the case of steel curbs with steel roof decks, welded. The roofing material or membrane runs up the side of the curb and a flashing system keeps water out of the curb/roofing joint.

Skylight Sizing and Structural Grid

Total skylight area is a function of the size of the skylights, the number of skylights and their spacing. SkyCalc software, an excel application, is available to help users calculates the total skylight area needed to optimize the trade-offs between lighting energy reduction, solar heat gains and thermal losses through skylights. The size and spacing of the skylights are partially determined by:

- Uniformity - the closer skylights are spaced together, the more uniform the daylight will be in the space. Greater ceiling heights or with splayed wells, allow skylights to be spaced further apart while maintaining uniformity.
- Cost - much of the cost of installing a skylight is in cutting the hole through the roof. Thus, fewer larger skylights will generally be less expensive than many smaller skylights adding up to the same total area.
- Structural spacing – Skylights are usually spaced apart on a grid compatible with structural grid, in order to avoid cutting beams, roof joists and other structural members. Also skylight dimensions will be sized to fit between joist spacing; thus the popularity of 4 ft and 5 ft wide skylights for steel decks.

Integration of T-bar and Other Components

This section of the report deals with historical examples of T-bar integration with other building components and 3 examples of current building designs using T-bar suspension grid in conjunction with other building components.

Historical Examples

This section deals with three historical examples of functional and structural integration by the ceiling industry over the years: flexible grid components; lighting integration components; mechanical system integrated components. Initially, these product offerings consisted of proprietary systems that provided air distribution, lighting, acoustical and, in some configurations, fire rated assemblies.

1. Grid components

Historically, the suspended ceiling grid system offered a lot of flexibility in combining various design features. The wide-track suspension grid was based on the structural modular grid of 5’ x 5’, but other sizes like 54” x 54” were also available. The grid provided structural attachment points for partitions; locations for fire sprinklers and electrical and telephone wire drops to the space below; signage support, etc.

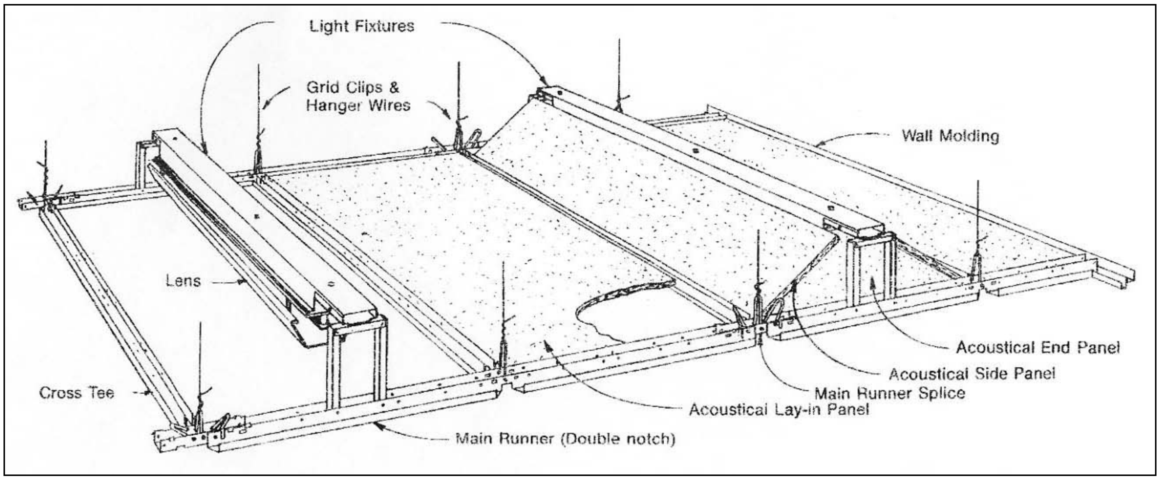


Figure 7: Ceiling grid system used in the 70s and 80s

(Source: Figure provided by Hemphill Interior Technologies)

2.Coffered Lighting

The most important functional advance was in the use of vaulted light delivery systems. These systems delivered significantly higher lighting efficiencies (i.e. more light to the room below for less energy) and in many cases were sold, especially to school systems, on energy cost reductions. Lighting quality was also improved over the recessed lighting troffers then available due to the reduced glare from the large luminous vaults. These systems used specially designed lighting fixtures and lenses, which were proprietary.

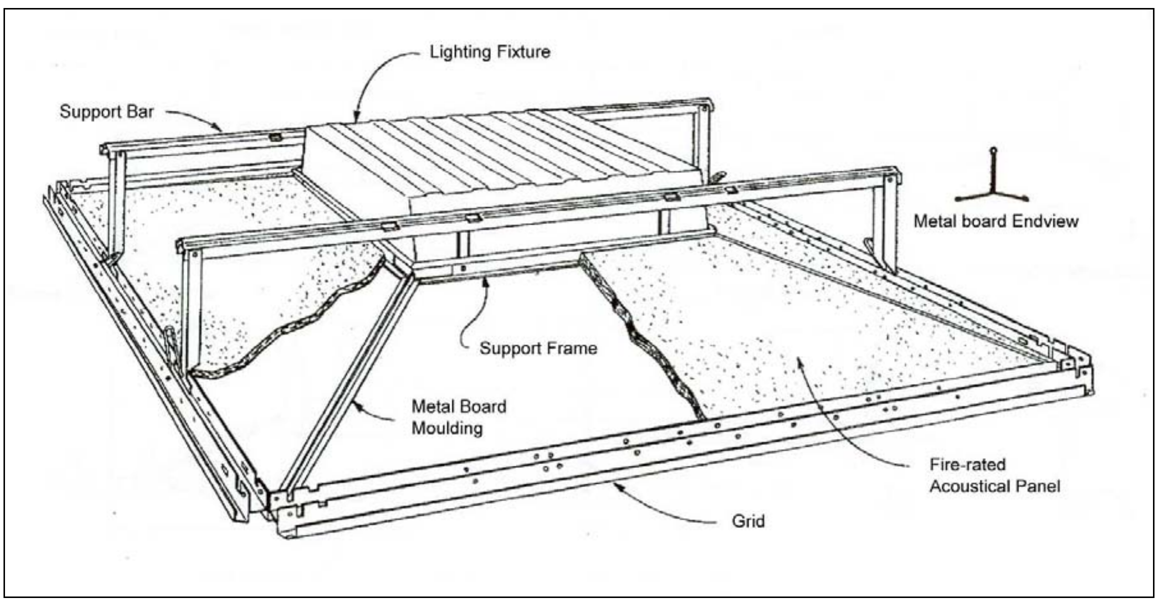


Figure 8: Splay system used in the 70s and 80s for vaulted (coffered) ceilings with lighting fixtures

(Source: Figure provided by Marshall Hemphill, Hemphill Interior technologies)

These systems fell into disuse for several reasons:

- Lighting specifiers did not like these systems as their fee was based on lighting system budget, not out of the budget for the ceiling system. In addition the lighting systems were often proprietary and did not allow the flexibility of choosing from multiple suppliers.
- The advent of the parabolic troffer offered many of the lighting performance features of the coffered ceiling at a much lower cost.

Nonetheless, these coffered ceilings provide a shape that is desirable for skylighting in that it increases the height of the source while spreading the light

3. In Grid HVAC Diffusers

Air distribution was accomplished by linear air diffusers integrated in to the “wide track” (typically 2” – 2 1/2” wide) structural ceiling grid. Specially designed air diffusion elements (boot and air bar) distributed conditioned air into the occupied space without drafts. Even diffusers that are not incorporated into the grid system are compatible with grid systems by virtue of their size. The diffusers typically are two feet wide in one direction (often in both directions). Thus the diffusers can easily drop down into the ceiling grid. If they are installed in a 2' by 4' system, the remaining space in the grid opening is filled by a ceiling tile cut to fit.

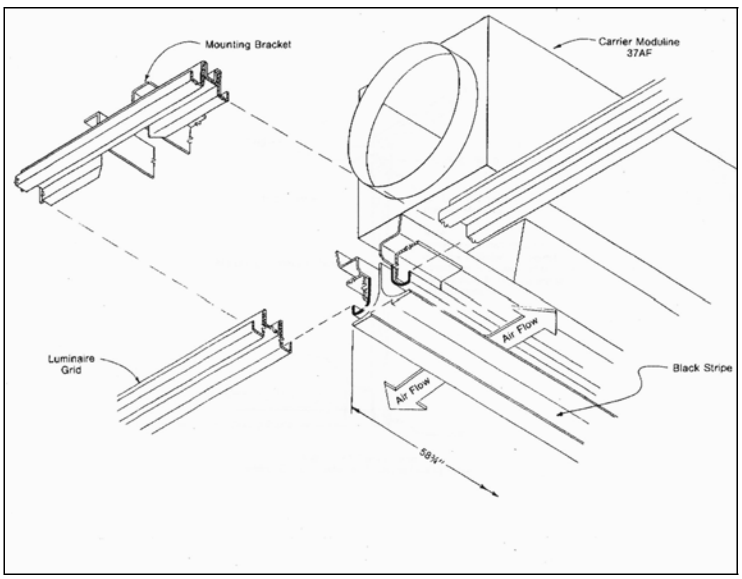


Figure 9: Carrier Moduline interface system for AC diffusers incorporated into grid system

(Source: Figure provided by Hemphill Interior Technologies)

Design Implications

As the initial proprietary integrated ceilings systems achieved market acceptance, resistance developed from the design, manufacturing and distribution communities because their traditional roles were compromised by these pre-designed, pre-engineered, systems. Traditional light fixture manufacturers were excluded from offering their products and electrical distributors could not package bids including some of their traditional elements. In recognition of this resistance, the ceilings systems manufacturers began to include fixture support frames (square and rectangle frames of traditional T- bar members) to locate and support commercially available 2' x 2', 1' x 4', 2' x 4', etc. recessed troffers.

As these systems evolved through the 20 plus years that the vaulted and wide track images were of interest to the design community, considerable design and product flexibility were brought into the product offerings. Design modules ranged from 3' x 3' up to 6' x 6'. Lighting options grew from 6" x 4' fixtures located at the top of the vault to standard fixtures of 2' x 2' to 4' x 4'. Lensed and parabolic options were designed to reduce glare on computer screens. Lighting fixtures could be installed flush with the ceiling or up to 12" above the ceiling line. All these variations resulted in a "kit of parts" provided by the ceiling manufacturer for a truly modular product that could be combined with lightng and mechanical systems.

Current Examples of Flexible and Sloped Ceiling Geometries

The following examples are based on product catalogs of manufacturers who have modified T-bar ceiling suspension grid system in combination with dropped ceilings, coffered lighting, and vaulted ceilings. These examples indicate that an integrated system of T-bars with skylights is a strong possibility.

Soffit Designs for Dropped Ceilings

These design modifications are some of the examples of current details being used in designs of dropped ceilings for commercial buildings.

1. Dropped ceiling for drywall

Gypsum soffits can be constructed with wood frames or with steel studs and runners with the board attached with screws. The ceiling or partition to which the soffits are to be attached have to be finished with gypsum board to retain its fire protection. Unbraced soffits without horizontal studs are suitable for soffits up to 24" x 24" in size. Meanwhile, braced soffits up to 24" deep can be constructed without supplementary vertical studs.

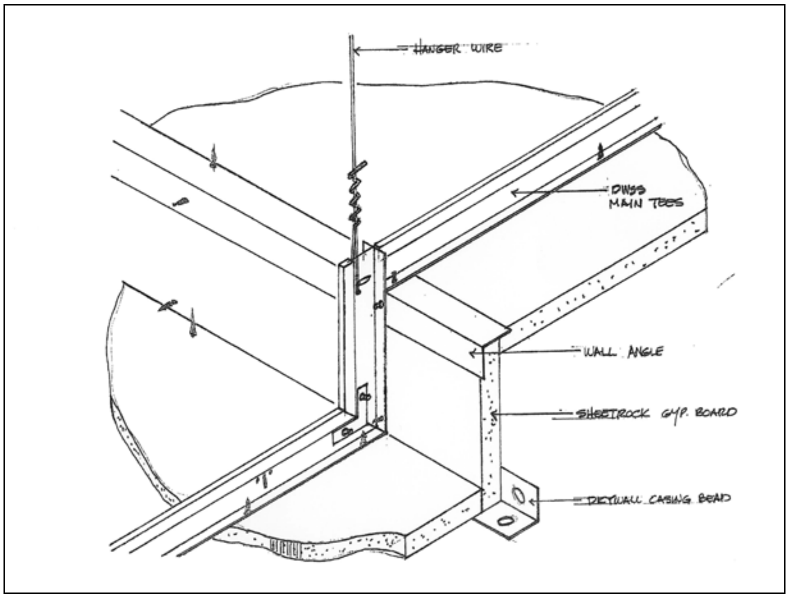


Figure 10: Section and view of drywall dropped ceiling details

(Source: USG catalog)

2. Dropped Ceiling design for Acoustical Tile Ceilings

Dropped ceilings with acoustical tile panels usually have the panels connected to the drywall with angle wall molding. At the point where the ceiling drops, the main tee is bent and secured with an angle bracket, which supports the acoustical panels (as shown in Figure 11).

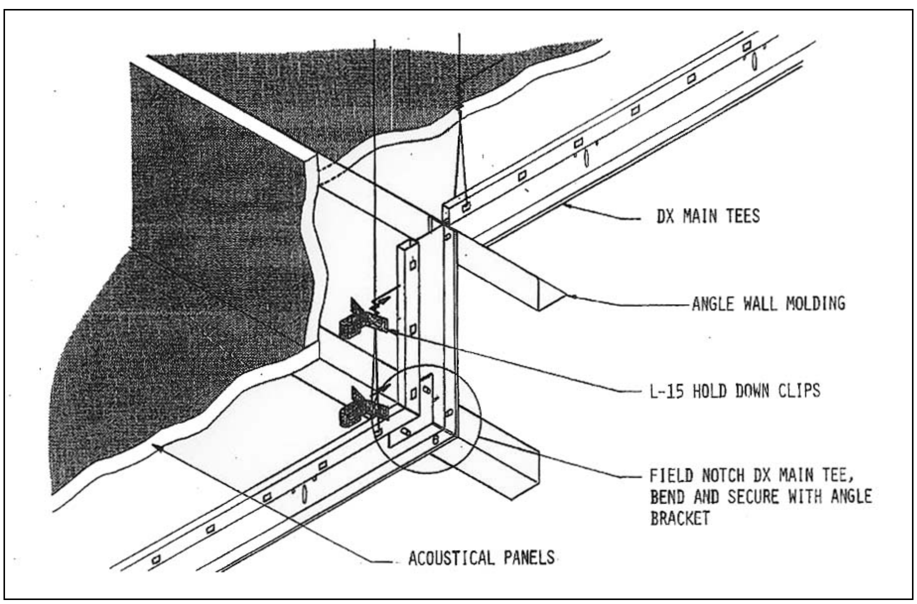


Figure 11: Section and view of acoustical panels dropped ceiling details

(Source: USG catalog)

Vaulted Ceilings

Figure 12 shows the view of a vaulted ceiling in section that consists of a metal connectors that is used to connect the vault to the horizontal gypsum ceiling. This connectors can be fixed at 90 degrees or flexible for any other angle required for the vaulted shape.

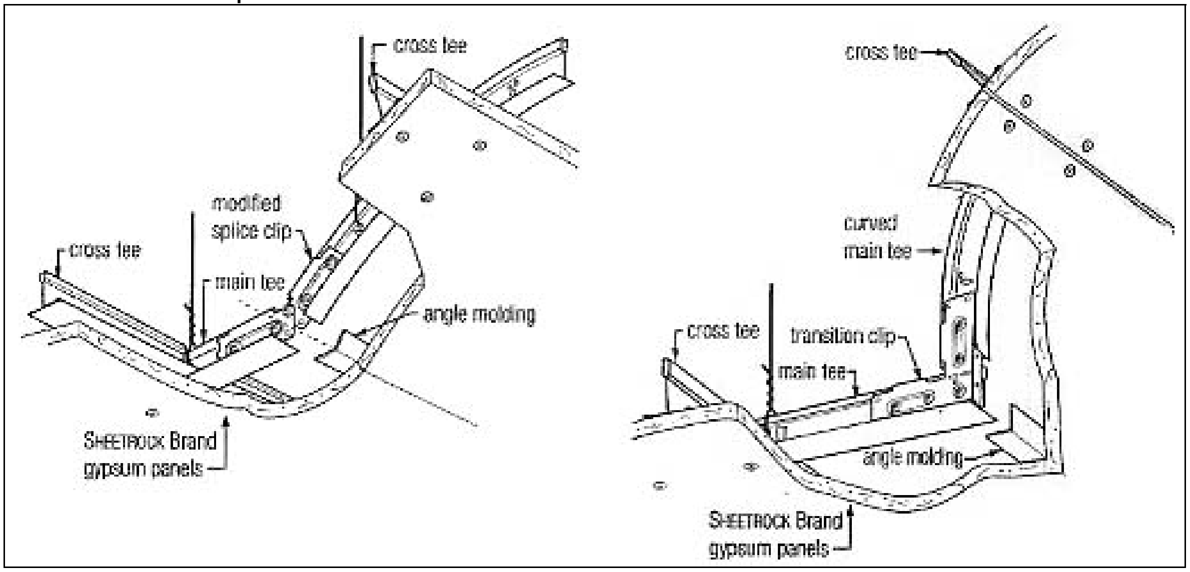


Figure 12: View of a vaulted ceiling with an angle connector (fixed at 90 deg or flexible for any angle) between the vault and the horizontal gypsum ceiling

(Source: USG catalog)

Spacing Issues in Construction

Horizontal Spacing of Roof/Ceiling Components

Total skylight area to optimize energy savings can be determined based upon the desired light levels and the overall efficiency of the skylight delivery system. The size of individual skylights and their spacing is driven primarily by the spacing of the structural members and roof deck panel sizes. The most common size of skylight for warehouses is the 4' x 8' skylight because it replaces a 4' x 8' sheet of plywood and the spacing of joists or purlins are often spaced 4' or 8' apart.

Four or five feet apart is a typical joist spacing for roofs with metal decks. Spacing of joists is a function of the loads and the thickness of the roof deck material. Thicker roof decks can support wider spans between joists.

The 2' x 4' T-bar ceiling grid is developed on a regular 4 ft spacing of main runners with secondaries spaced 2 ft apart. The smaller 2'x 2' grid adds extra runners through the secondaries. Ideally the bottom edge of the light well where it intersects the ceiling falls on the main runners in one direction and the secondaries in the other direction. It is virtually impossible to line the skylights up with the ceiling grid especially when the spacing of skylights is not in multiples of

4 ft. Thus for an integration system configuration to account for a tolerance of at least a foot horizontally, becomes an important consideration.

Consideration should also be given to placing HVAC diffusers next to light wells. When the HVAC system is providing cooling, the distance that the supply air is spread is based upon the flow of air "attaching" to the ceiling surface. When the diffuser is adjacent to the light well, the lack of a horizontal surface adjacent to the diffuser will result in the cold air from diffuser dropping with minimal mixing - which could cause a comfort problem. Discharging air away from the light well for a one-way system, can be one option.

Electric lighting and skylighting need to be designed so that both are complementary and the electric lighting can provide suitable uniformity at nighttime. If the light wells are large, the lighting design must span these distances somehow, either by placing a suspended fixture beneath the light well or by placing a fixture inside the light well. This second path is the concept behind "hybrid" lighting systems that are a combined daylighting system and lighting fixture in the same assembly.

Controlling electric lighting is simplified if there is a regular pattern of the lights that are closest to the light well, those at an intermediate distance and those furthest away. This would imply a spacing of skylights that are a multiple of he spacing distance of electric lights.

Sprinklers are typically are spaced every 100 SF. In addition some jurisdictions will require sprinklers up in the light well to protect its surfaces. When the light well opening in a ceiling is large it takes some planning to place the sprinklers around the edges of the light well opening while maintaining good overlapping coverage.

Vertical Spacing - Separation of Trades

The plenum space between the roof deck and the ceiling hides a host of building components: electrical conduit, sprinkler pipes, HVAC ducts, recessed light fixtures, control and communication cabling, structural members (beams, joists and purlins) and the hangers for most of these components. The construction manager's and the designer's jobs are made much easier if vertical layers are allocated for each of the building trades–if a layer is specifically allocated for ducts, you don't have to worry about beams or conduit getting in the way. *Figure 13* illustrates typical depths allocated to building component layers and the range of depth expected for the plenums and ceiling heights considered for this project.

Since the more plenum space allocated increases the building cost, there has to be a balance between cost and ease of construction so that the allocated layers are not too generous. Sometimes HVAC ducts have to be threaded through the structural members.

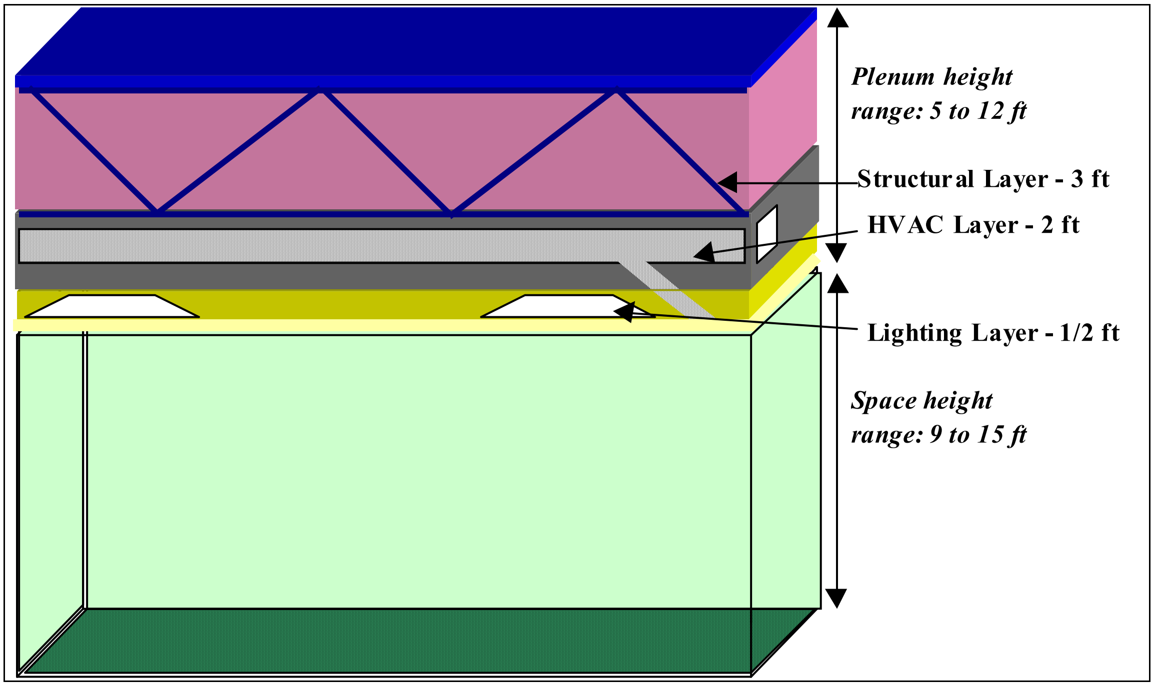


Figure 13: Vertical Building Component layers

This vertical separation of trades by horizontal layers in the plenum is upset by the addition of the light well, which punches through all of these layers to bring light from above the roof plane through an opening in the ceiling. Since there are so many competing components hidden in the plenum, the light well design protocol must either be flexible to thread itself through these components or must stake a claim early on to its desired path through the plenum.

CASE STUDIES OF SKYLIGHTS WITH T-BAR CEILINGS

This section deals with eleven case studies of offices, schools, grocery and retail stores with skylights and T-bar ceilings. These case studies were based on site visits, interviews with architects and construction managers and review of building plans.

1. Grocery Store A – System 1

The description of this case study is based on site visit, interview with the construction manager and building drawing study. Grocery Store A is a chain grocery throughout the New England area. Because of their extensive construction activity, they try to maintain a consistent store design throughout the region. This resulted in the use of a prototype store plan that they revise according to specific site limitations.

At present, they have six skylit store locations in three states. They have experimented with two different systems for their applications. System 1 is the first one installed. Because of the high cost of System 1, it was redesigned for applications in all other subsequent stores. Other stores used System 2, which is their new prototype system.

Here, we will discuss System 1, while System 2 will be discussed in the following case study.

Design and Planning

The sales area is subdivided into 4 major sections: produce, general products, health and beauty and checkout. The produce and checkout areas are covered by a vaulted ceiling system to provide contrast to the other areas of the store. A drop ceiling covers the general products and health and beauty sections with skylights distributed throughout. The ceiling is 14’ high.

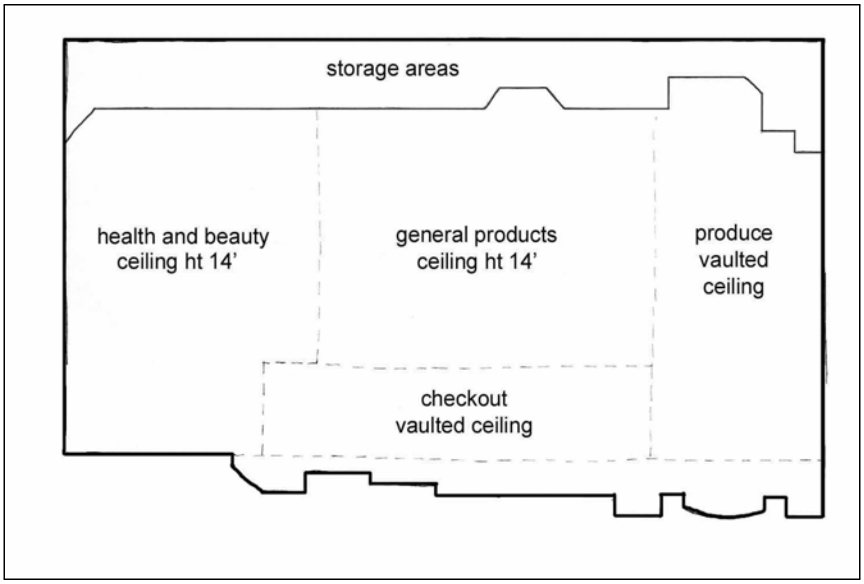


Figure 14. General store layout.

Skylights were provided for ambient lighting. Therefore, they were located as much as possible over the circulation space. But gondolas or shelves positions are flexible and expected to change throughout the life of the building. Though skylights are roughly positioned to correspond to aisle placements, they also try to accommodate future changes in shelf positions.

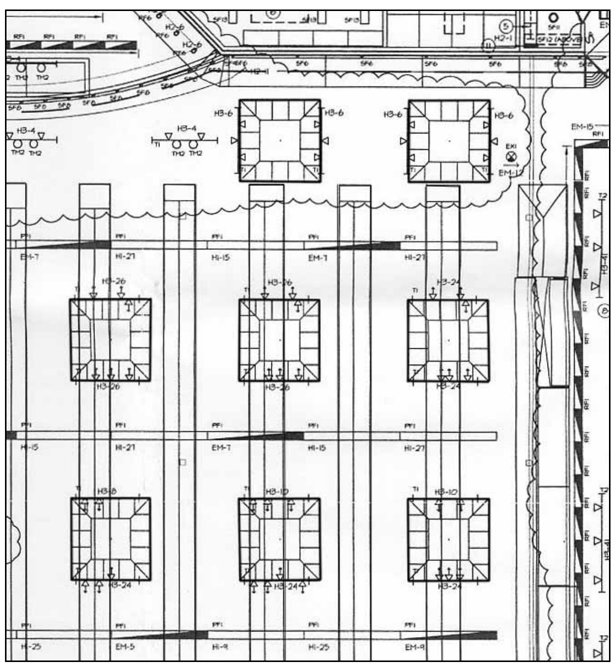


Figure 15. Skylight layout relative to gondolas / shelves.

Light Well Construction

The skylight is 5'x5' in dimension and located atop a flat roof, gently sloped for water drainage. It is a high performance skylight system, using a heat mirror. Because the skylight has a deep well, direct sun is always intercepted by the well and hence no diffuser is required at the bottom of the throat.

The glass is a double-glazed configuration. The outer layer is tempered glass and the interior layer is heat-strengthened laminated glass coated with pattern # 62 film that makes it translucent. A coated heat film is also sandwiched between the two glass layers. The glass surface is slanted on a 4:1 angle and oriented facing south to catch the sunlight.

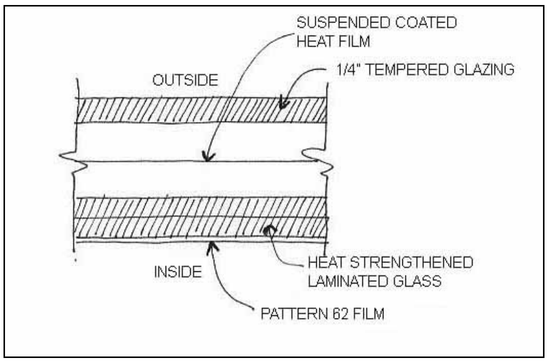


Figure 16. Skylight glass configuration.

Figure 17. Construction of skylight curb

(Source: Unique Commercial Applications of Light Pipes, Ensar Group, Inc.)

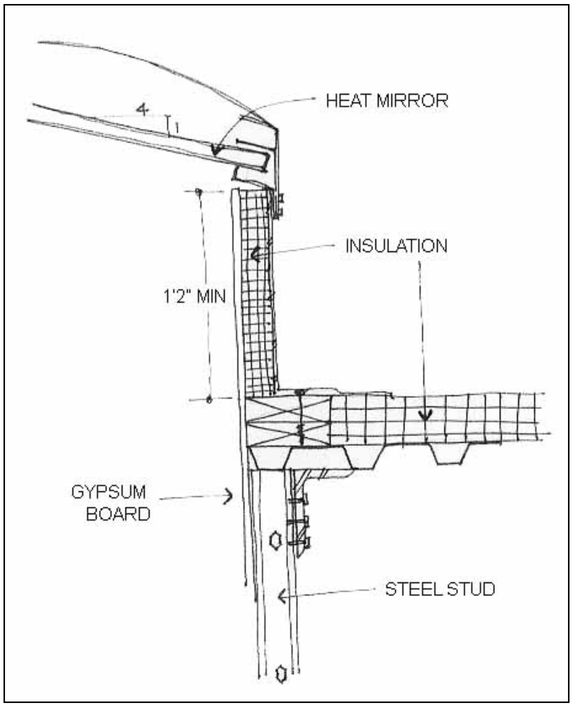


Figure 18. Curb section.

A light well goes 8’ down to the ceiling of the sales area. The throat opening is also 5’ x 5’. A splay with a height of 4’2” extends from the throat to the ceiling opening. Light well opening in the ceiling is 10’ x 10’.

Skylights located over the produce and checkout counters have a different design. They have perforated metal curved reflectors to diffuse the daylight coming in through the light well by reflecting them off the white ceiling. The perforations also allow some light to filter directly down into the sales area.

Figure 19. Produce section reflector.

(Source: Unique Commercial Applications of Light Pipes, Ensar Group, Inc.)

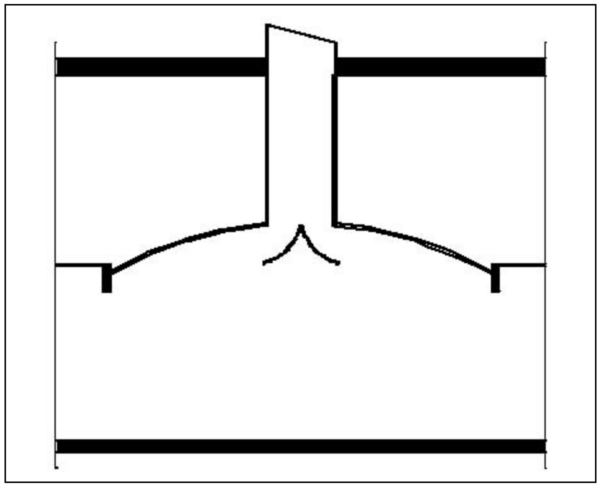


Figure 20. Section through light well with reflector.

(Source: Unique Commercial Applications of Light Pipes, Ensar Group, Inc.)

Ceiling Tile Pattern

Ceiling tiles are 2'x4' in size. They are oriented with the short side along the frontage of the building. Ceiling tile design was coordinated as much as possible with the skylight locations. But due to the mismatch in dimensions of the skylight opening (10' x 10') with the tile size, no consistent pattern was evident in the tile design relative to the skylight. Variable site conditions as a result of imperfect workmanship also resulted in a mismatch in the designed tile pattern.

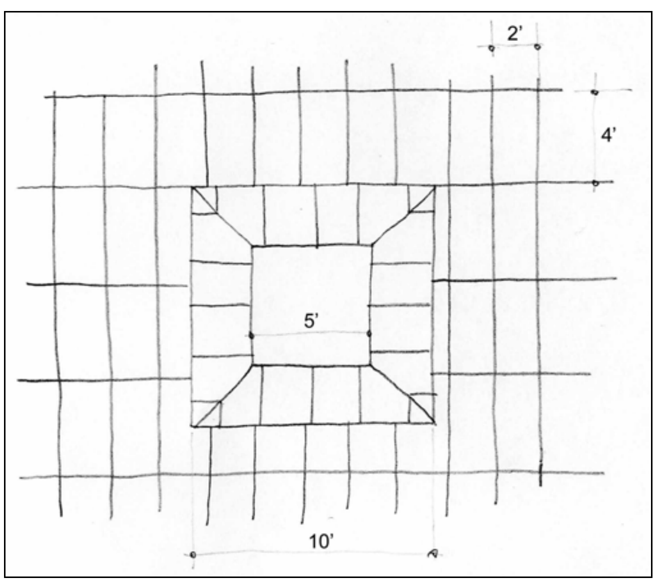


Figure 21. Tiling pattern of ceiling and splay.

The splay tile pattern was also not matched to the ceiling tile pattern. The design and dimension of the splay necessitated the use of special order 2'x5' tiles instead of the standard 2'x 4'. But this also resulted in delays when certain tiles required replacements.

Daylighting and Lighting Controls

The lighting level is controlled by a photocell sensor. It is located in the center of the store and oriented facing up into the light well.

Materials

Item	*Material*
Ceiling Tiles	2' x 4' ceiling tiles
Splay tiles	2'x5' ceiling tiles
Light well	White painted gypsum board
Skylight glazing	High performance glass
Lens	none

Capital Costs vs. Energy Savings

The skylight system cost $3,300 per installed skylight and well. Because of its high cost, they decided to redesign the system. What resulted was System 2, which is the new skylight prototype being used for all new stores and is 2/3 the cost of System 1.

2. Grocery Store A - System 2

Design and Planning

The store design for Systems 1 and 2 are similar. The only difference is the ceiling heights. While the ceiling height for System 1 is flat throughout the sales area, the ceiling heights for System 2 vary according to their function. The general products area has a 14' high ceiling while a lower ceiling height of 12' is designated for the health and beauty section because they wanted to achieve a more intimate shopping environment for these personal products. The checkout and produce areas still have vaulted ceilings.

Light Well Construction

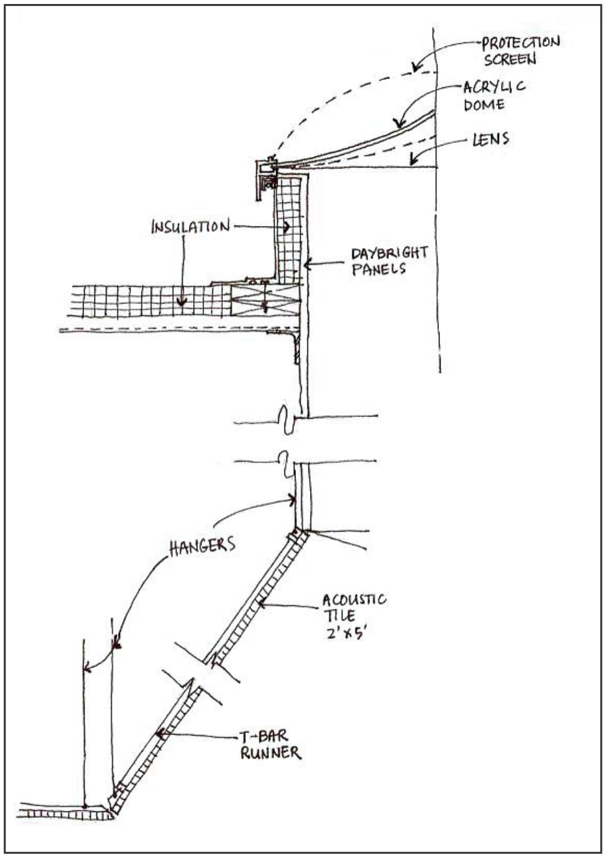


Figure 22. Section of skylight system.

Skylight opening in the ceiling is 10’ x 10’. The opening of the throat is 5’ x 5’. It is covered by a prismatic acrylic lens for light diffusion. The well of 5’ x 5’ dimension goes all the way up the roof opening.

Splay slopes and heights and throat heights vary according to the light well. For the health and beauty sections (12’ ceiling height), the splay height is 4’2”, while for the general products section (14’ ceiling height), it is 3’1-1/2”. This difference in height is to allow for a different splay slope and thus, allowing more light to spread throughout the general products area.

Well heights also vary according to the interior ceiling height and exterior roof slope (for precipitation drainage). The health and beauty section has well heights of about 10’, while the general products section has well heights of about 8’.

Connectors

All connectors used in the splay are standard parts of a T-bar ceiling suspension system. No custom-made parts were necessary. The three most important connections are between the ceiling and the splay, and between the throat and the splay and the diagonal members.

Below are two connection details:

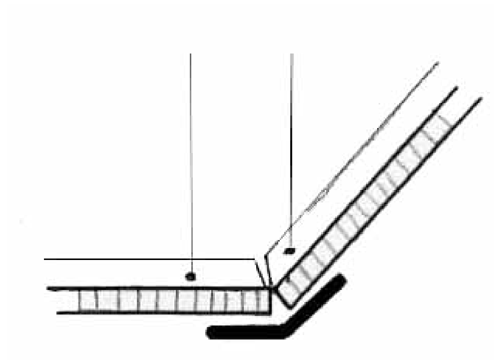


Figure 23. Connection of ceiling to diagonal members.

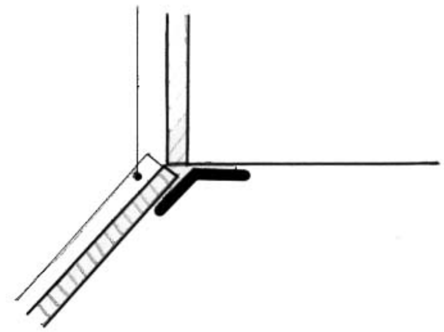


Figure 24. Connection of throat to diagonal members.

Ceiling to splay connectors are edge sections of T-bar suspension systems, while the supporting system of the splay are T-sections suspended by hangers to the ceiling.

Building Systems Coordination

One of the major problems foreseen with the use skylights is the way it interacts with the various systems with a building, such as the mechanical ducts, sprinkler pipes, and structural grid.

The planning of a store for this retail chain begins with the design of roof structural plan. Roof load is determined mainly by the two penthouses located atop the roof deck: electrical and refrigeration. The load calculation determines the steel framing plan required for the building.

This framing plan is then forwarded to the lighting consultant. The consultant determines skylight placement according to the structural grid, and gondola/shelf locations. Because the intent of the skylighting system is to provide ambient lighting, they are located as much as possible along the aisles.

Thereafter, all other major consultants determine their designs and layouts according to the structural plan and skylight locations.

Ceiling Tile Pattern

Ceiling tiles are 2’x4’ in size and have the same layout plan as the store 1.

Daylighting and Lighting Controls

Lighting is controlled by a central system based in corporate headquarters. The store uses a dimming system to allow for daylighting savings due to the skylights. Light level settings are adjusted seasonally and they are monitored by photocell sensors installed within the splay of the skylight, as shown in Figure 25.

Figure 25. Photosensor location in splay.

Fire Code

A sprinkler head is located inside the light well of the skylight. It is placed about 10" below the top of the well. NFPA also requires an additional sprinkler in the splay should the splay height exceed 36".

All skylights in the store have sprinkler in the light well, but only skylights in the 12' ceiling have sprinklers in the splay.

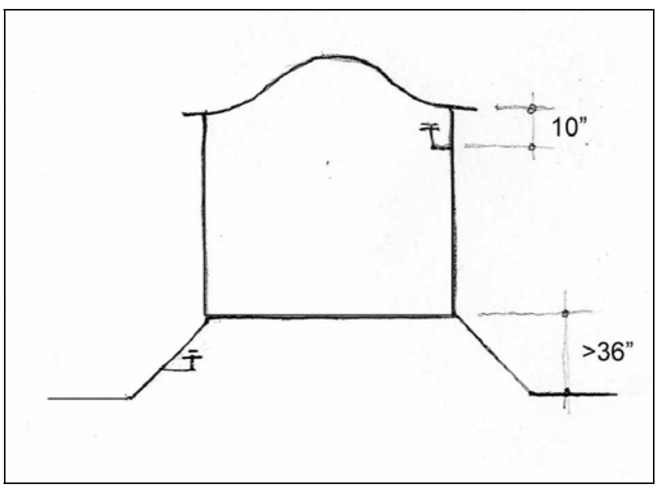


Figure 26. Sprinkler locations.

Materials

Item	*Material*
Tiles	2' x 4' or 2'x5' acoustic tiles
Connectors	White enamel-painted metal t-bar system
Diagonal members	White enamel-painted metal t-bar system

Light well	97% reflective daybright panels
Lens	Clear acrylic prismatic lens

Capital Cost vs. Energy Savings

The system costs about $1,600 to $2,000 each skylight. The most costly element of the system is the 3M reflective film used to coat the light well to maximize daylight coming through the skylight. Approximately $300 to $400 of the total cost goes into installation labor costs.

One of the main objectives of the system was to minimize the electricity costs of the stores. Therefore, they had monitored the differences in costs of the skylit stores against their conventional stores. Their results show about 30% reduction in total electricity costs. But it cannot all be attributed to the daylighting benefits from the skylight. About 20% of it comes from savings due to the use of fluorescent lights (that replaced metal halide lamps) and better ballasts.

Because of these results, the skylight system is not a cost-effective strategy. The planning group would like to see about a 50% reduction in the system's initial cost. Despite the cost issue, they will still continue implementing the skylight design in future stores because of the improved ambient lighting quality it provides.

Problems

The case study store experienced extensive water seepage problems. The main cause was determined to be cracks in the skylight frame and faulty flashing system. All ceiling tiles had to be replaced prior to store opening. But a short 4 months after opening in November, there are again evidences of new seepage problems, both in the skylight and on the ceiling (see photo below).

Figure 27. Seepage in splay.

Figure 28. Seepage in the ceiling.

Because system is customized, there is little coordination between design and construction. Implementation methods and problems were resolved on site. These resulted in inconsistent workmanship, such as an irregular tile piece, gaps in construction, ill-fitting tiles and column going through the splay.

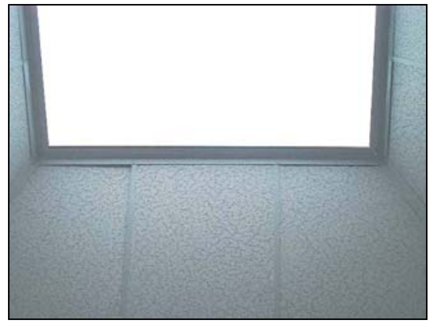


Figure 29: Gaps in construction, ill fitting tiles, column placement through the splay

3. Olive Ranch School

The Olive Ranch School in Roseville, California is an elementary school which was under construction during our site visit. The school consists of 24' x 40' classrooms installed with four skylights per classroom. This case study report is based on site visit, interview with the architect and review of building plans.

Roof

The roof is sloped with heights varying from 8' to 13 feet ceiling height at the center of the classroom. The roof layers are as follows: The structural components consist of metal I-beam as the central ridge supported by 2x6 wood blocks between roof joists, with metal purlins. The roof deck is made of plywood with batt insulation below the metal deck.

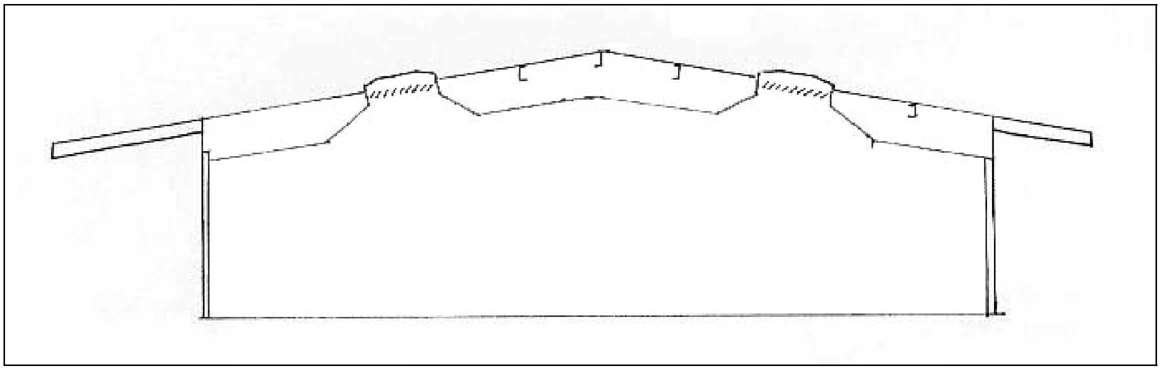


Figure 30. School building section.

Ceiling

The ceiling is made of acoustical tile panels with metal T-bar suspension grid system of two feet by four feet dimension.

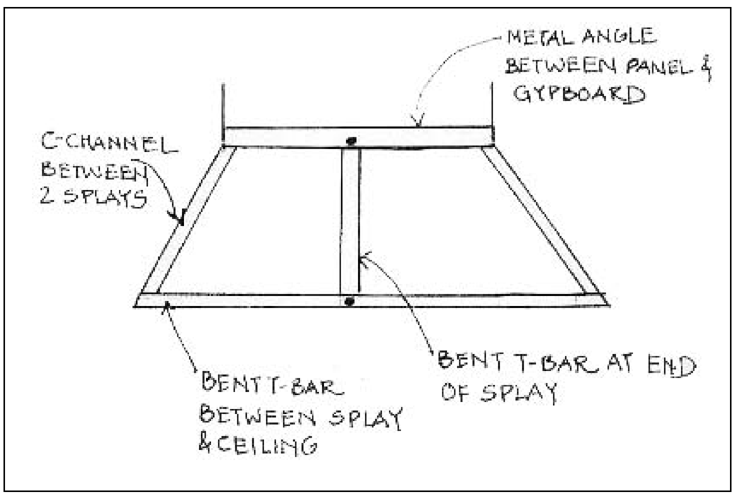


Figure 31. Ceiling systems used in splay.

Figure 32. Splay construction detail.

4. SMUD Customer Service Center, Sacramento

The customer services building of the Sacramento Municipal Utility District consists of typically 4 feet by 6 feet skylights spaced on a 24 feet by 20 feet grid with 12 feet by 12 feet splayed light wells.

Roof construction

The roof construction consists of a metal deck with rigid insulation over the deck and EPDM single ply roofing. Below the metal deck is structural framing with I-channels riveted on to the metal deck.

Skylight details

The translucent skylight material is a triple layer of plastics with a prismatic layer sandwiched between clear layers to diffuse direct sunlight. The daylighting is controlled by louvers, with the louver motor being located along the skylight curb. The skylight curb is supported by a metal bent plate wrapped over the curb and coated with exterior flashing.

Light Well construction

The light well is made of 5/8" gypsum board with the vertical portion of the well being 4 feet high and the splayed portion (also made of gypsum board) being approximately 5 feet high. During construction, the skylight well extent was lined out on the floor slab and the contractor built "Ribs" out of metal studs. These ribs were all the same shape and sized. These ribs were then laid out side by side spaced approximately 16"o.c. and tied together with stud tracks. The well framing was built on the floor and then hoisted up to the roof structure and secured in place. After the framing was complete the framework was rocked, finished, textured and painted. A simple shadow mold is used between the edge of the gypsum board skylight well and the ceiling. The sloped portion of the skylight well terminates with a horizontal gypsum board soffit piece so as to create a transition between the gypsum board and the ceiling panel.

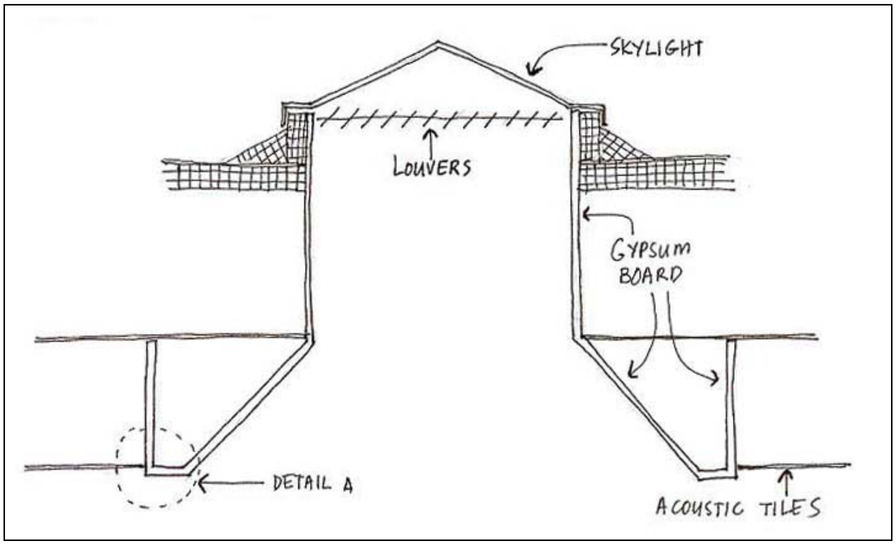


Figure 33. Section of skylight system.

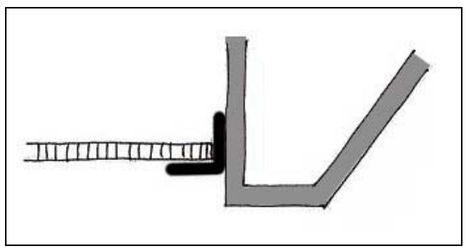


Figure 34. Detail A, connection between gypsum splay and acoustic ceiling tile.

Figure 35: View of top floor skylight above work desks

Ceiling

The ceiling height is 11 feet and is 2' x 2' with a metal suspension grid system. The T-bar ceiling is connected to the splayed portion of the gypsum board with a metal angle.

Electric lighting

The electric lighting is a combination of direct/indirect luminaires with dimming ballasts running continuously north to south across the space, mounted at approximately 8' height. Each work station is also provided with a task light.

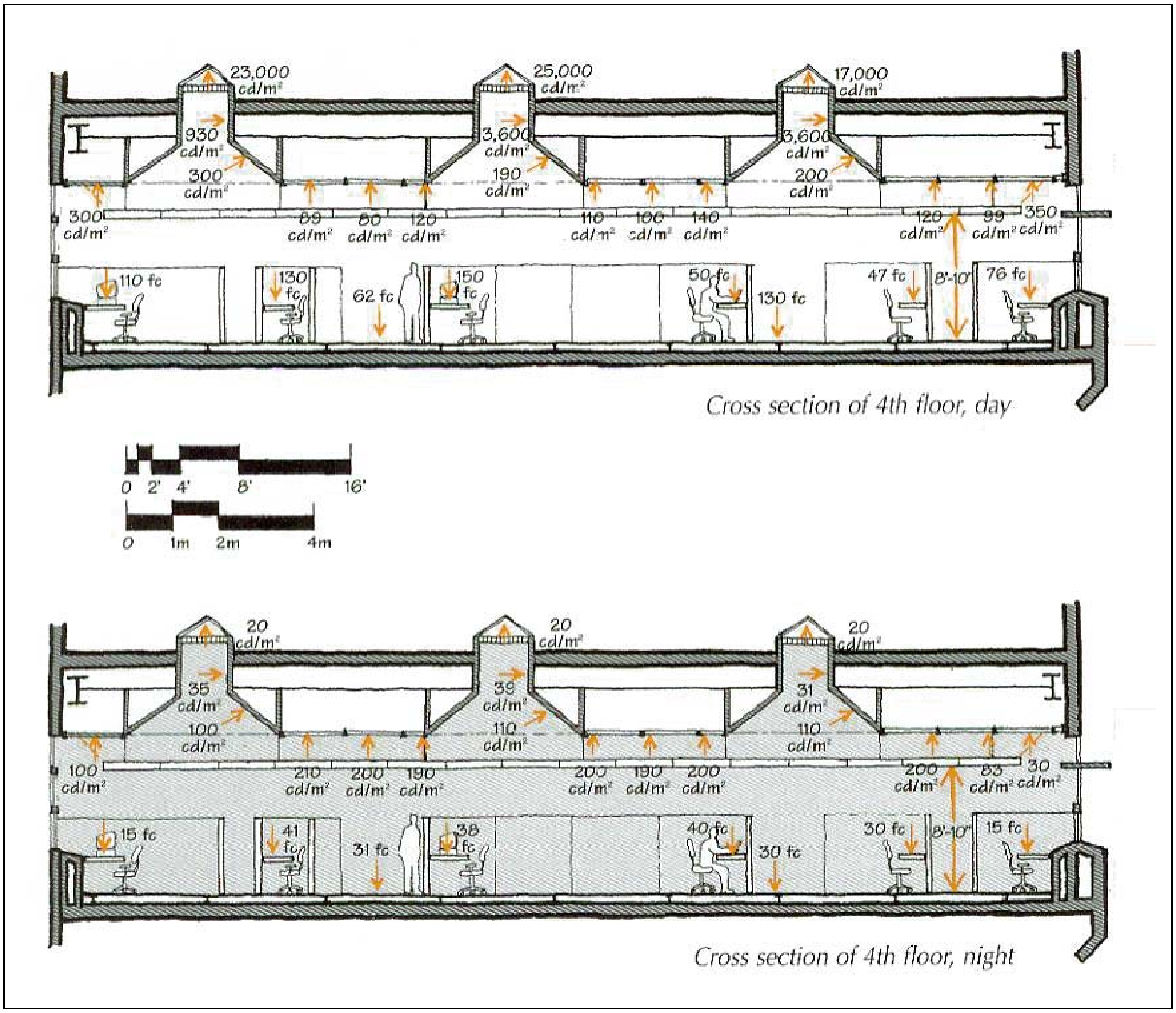


Figure 36. Light levels from skylight and electric lighting in the office, during the day and at night.

(Source: Delta Portfolio, lighting case studies, volume 2, issue 2)

5. CSAA Office Building, Antioch

The California State Automobile Association district office in Antioch, California has skylights as part of their daylighting design. This building was designed as part of the Pacific Gas and Electric E3 program to develop exemplary energy saving buildings. The office space at CSAA in Antioch offers a spacious interior with high ceilings, advanced skylights, high performance glazing, perforated blinds and automated lighting controls. This case study is based on published material on this building (Daylight initiative, design tools and information from PG & E).

Skylight

Twenty nine triple-pane, acrylic, low-glare skylights spaced approximately 20 feet apart, have a combined area equivalent to 3.7 percent of the floor area. Skylight wells are splayed at a 45 degree angle to provide optimal light quantity and distribution. Louvers installed at the top of the skylight wells are controlled by photocells and these controls open and close the louvers to modulate the amount of light entering the building. The dimensions of the skylight are 4' x 4' with 8'x 8'splayed light well. The vertical throat of the light well is approx. 4' high and the splayed portion another 4' high.

Figure 37. Skylit office.

(Source: Daylight initiative- design tools & information from PG & E).

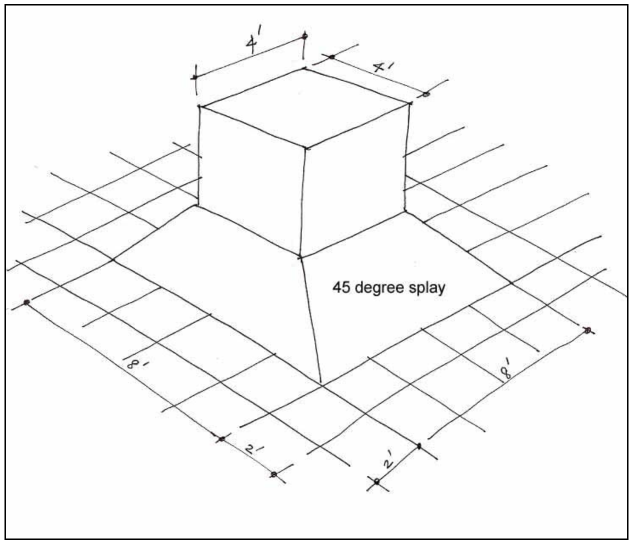


Figure 38. Light well location and ceiling tile pattern.

Ceiling

In the center of the building, the ceiling height is vaulted to 15 feet while the perimeter ceiling is at 10 feet. The ceiling consists of 2' x 2' acoustical tile panels.

Exhaust vents

Barometric exhaust vents are located in each skylight that provide building pressurization control and solar heat exhaust from skylight wells to reduce heat gain through the building.

Electric lighting

Dimmable electronic ballasts are incorporated in highly efficient T-8 flourescent fixtures to allow continuous dimming control and maintain interior light levels.

6. Williams + Paddon Office Space

Introduction

Williams + Paddon office building is a design firm offering architecture, planning and interior design services and is shared by an accounting firm. Skylights are installed in various locations in the building: lobby, conference rooms, and office spaces (including William + Paddon's spaces). Different locations used variations on similar skylight systems. The lobby skylights have vertical light wells with no splay that has the same interior opening dimension as the exterior skylight. The W+P offices space has skylights without T-bar ceilings, while other offices have skylights with splayed light wells with T-bar ceilings.

Figure 39. Office building with skylights on the rooftop.

(Source: Williams + Paddon Architects)

Figure 40. Skylight system for main lobby and conference rooms.

(Source: Williams + Paddon Architects)

Figure 41. Skylight system for the tenant offices.

(Source: Williams + Paddon Architects)

Design and Planning

Skylights are not located in any way to correspond to the use of spaces below. They are mainly coordinated with the structural and ceiling grid.

Light Well Construction

Skylights are of two dimensions: 4'x4' for the lobby, conference rooms, or 4'x8' for the main offices. For the lobby space, the light well extends vertically down from the rooftop to the lobby space with a dropped ceiling.

For the other offices, the light well with splay is used. Splays were added to maximize diffusion provided by the lens and give better light distribution. The splays are at 45° angle and can be adjusted to splay on different sides to align with the t-bar ceiling grid pattern.

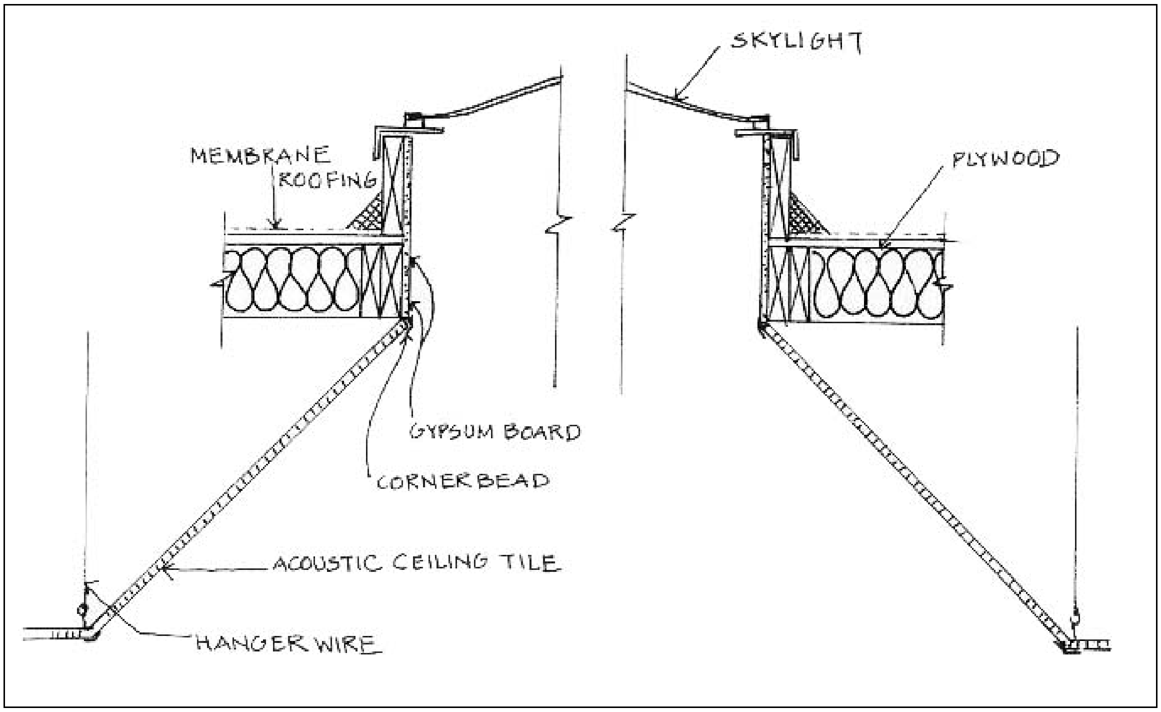


Figure 42. Section of typical skylight system.

Connectors

Connectors are standard t-bar suspension ceiling accessories. Angles were used, but bent on-site to accommodate the angles of the splay or other required connections.

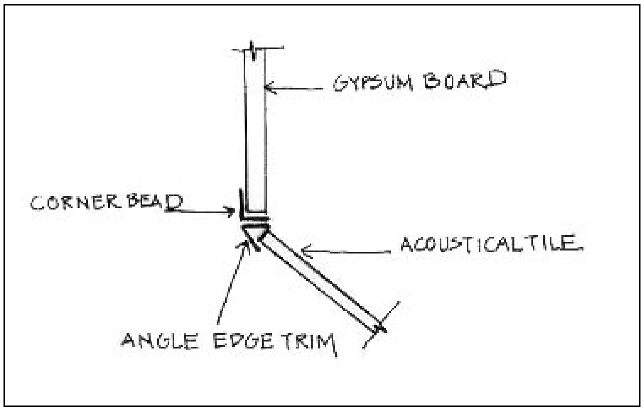


Figure 43. Detail of typical throat to splay connections.

Building Systems Coordination

No notable problems in systems coordination were encountered.

Daylighting and Lighting Controls

Electric lighting is switched by photosensor controls. They detect daylight levels and adjust the electric lights accordingly.

Fire Code

Sprinklers were not required in the skylight systems for this particular office space.

Capital Costs vs. Energy Savings

Spaces with open ceiling spaces costed $0.40 to $0.60 more to finish than t-bar ceiling spaces This extra cost was added because of the exposed duct design and finish material for the ducts.

Problems

No problems were observed in the system during occupancy.

7. School, San Juan Capistrano

The Capistrano School district is one of the fastest-growing districts in Southern California. In response to complaints about windowless classrooms, natural light was mandated by the board in the early 1980s. This school in San Juan, Capistrano was designed by PJHM Architects. This case study is based on published material on this school building and interview with the architect.

Design and Planning

Classrooms are about 34' x 34' in size with a 9' high ceiling. They are finished with 2' x 2' ceiling tiles. The roofing system is typically a built-up roofing system. In some towns, sloped roofs are required for the schools. Therefore, skylights are simply mounted on top of the sloped roof. Sometimes the glazing tint is chosen to match the roofing material. This architectural treatment resulted in a reduction of light levels in the interior space. To compensate, architects have used a longer slope and a more reflective light well to maximize daylighting.

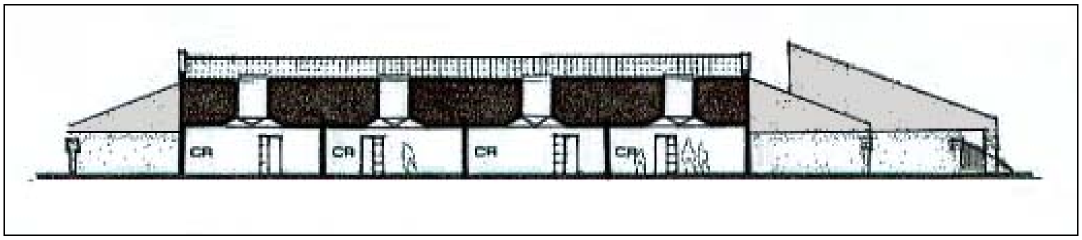


Figure 44. Capistrano School section.

(Source: Energy Design Resources, Southern California Edison)

The public areas, such as the library and the multi-purpose areas, have a higher ceiling height.

Light well Construction

Each classrooms has one 6' x 6' clear plastic skylight, with a 14'x 14' light well. An aluminum louver system is mounted below the skylight. The louvers can be controlled to adjust the amount of light entering the classrooms. In public areas, the louvers are controlled with an electric wall switch, similar to a light dimmer. With the louvers closed, the skylight provide about 10fc of light, just enough for video presentations.

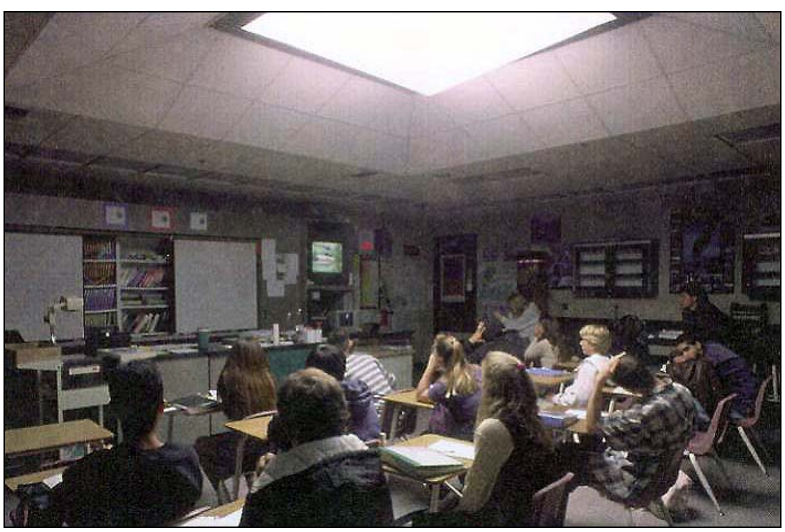


Figure 45. Classroom dimmed for AV presentation.

(Source: PJHM Architects)

Figure 46. Classroom lit for regular activities.

(Source: PJHM Architects)

The throat is 2' high, made of 5/8" insulated gypsum board and is covered by an inverted pyramid-shaped plastic diffuser. It helps reduce heat transfer and keeps hot air within the light well. The skylight then splays 2' to meet the ceiling tiles.

Hanger wires supporting the t-bar ceiling and the t-bar splay are spaced 3' apart.

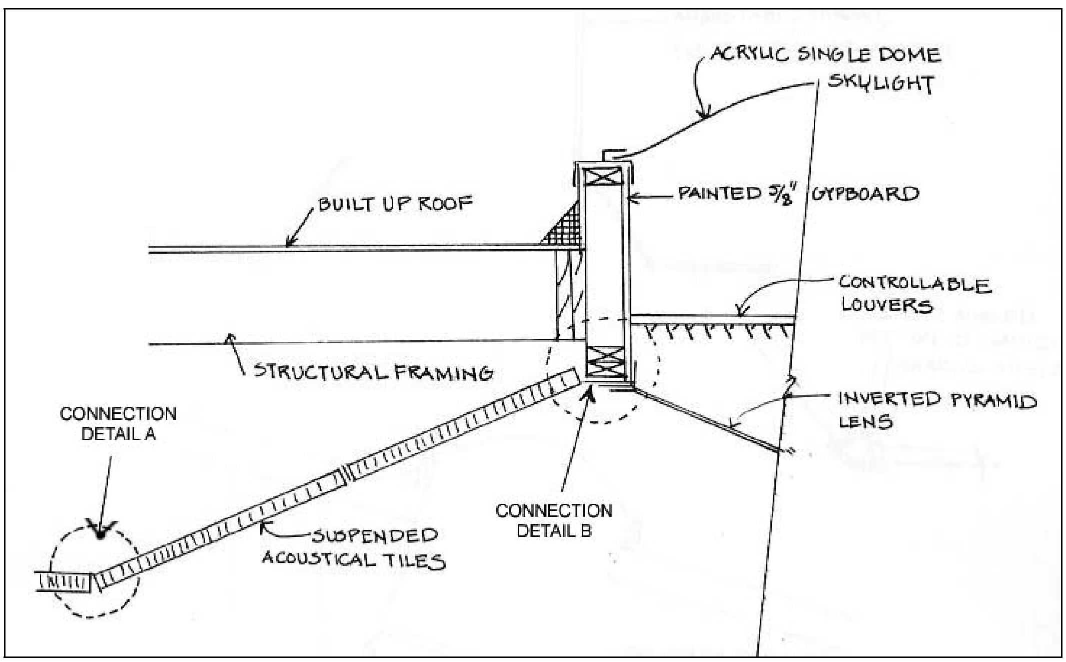


Figure 47. Section of skylight system.

Connectors

Connectors used in the system are metal angles and t-bar main runners. The connection between the ceiling and the diagonal splay member is a t-bar runner, while the connection between the throat and the diagonal splay member is a metal angle. See the drawings below for details.

Below are two connection details:

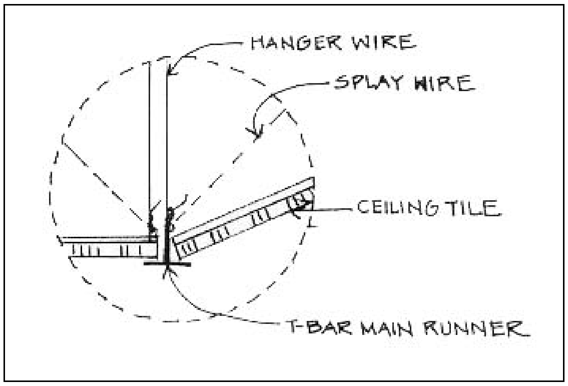


Figure 48. Detail A, connection of ceiling to splay.

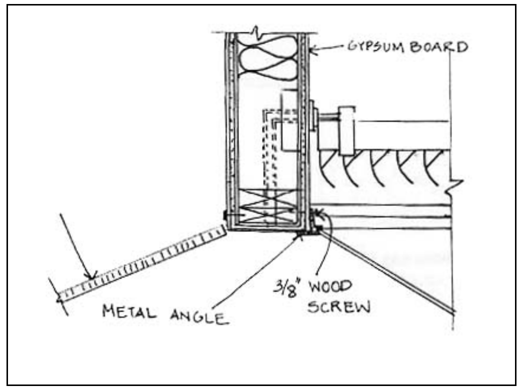


Figure 49. Detail B, connection of splay to throat.

Ceiling Tile Pattern

Because the ceiling skylight opening (14'x14') size is a multiple of the tile size (which are 2'x2'), matching patterns are easier achieved. The only irregularity present is in the corner conditions of the splay.

Daylighting and Lighting Controls

An electric light system supplements the daylighting provided by the skylights. There are twenty recessed 2x4 fluorescent fixtures going around the sides of the skylight. They provide an additional 25 to 30fc (vertical) on the walls during the day and an average of 50fc (horizontal). They are made up of two T-8 lamps with electronic ballasts. Half the lamps can be turned off at any time. Some classrooms have a third switch for turning on the lamps near the board to allow for better visual quality on the lecture board.

Materials

Item	*Material*
Ceiling	2' x 2' ceiling tiles
Light well	White Gypsum board
Splay	Ceiling tiles (irregular size)
Skylight	Clear acrylic
Lens	Plastic diffuser

8. Oak Ridge School

Introduction

Oakridge High School in Eldorado County, required 40 classrooms for 2,000 students. A design team with energy-efficiency and lighting experience (Nacht + Lewis Architects) came in with ideas for improved efficiency design, including daylit classrooms. This case study is based on interview with the architect and site visits made couple of years back.

Design and Planning

The school building was designed as a long rectangular building with two classrooms located back-to-back sharing a common wall. The common wall of the classroom is toplighted by a row of skylights washing the inner wall with daylight, while the opposite wall has a row of windows 9' high to provide additional daylighting. The window face either north or south, depending on which side of the building the classroom is located.

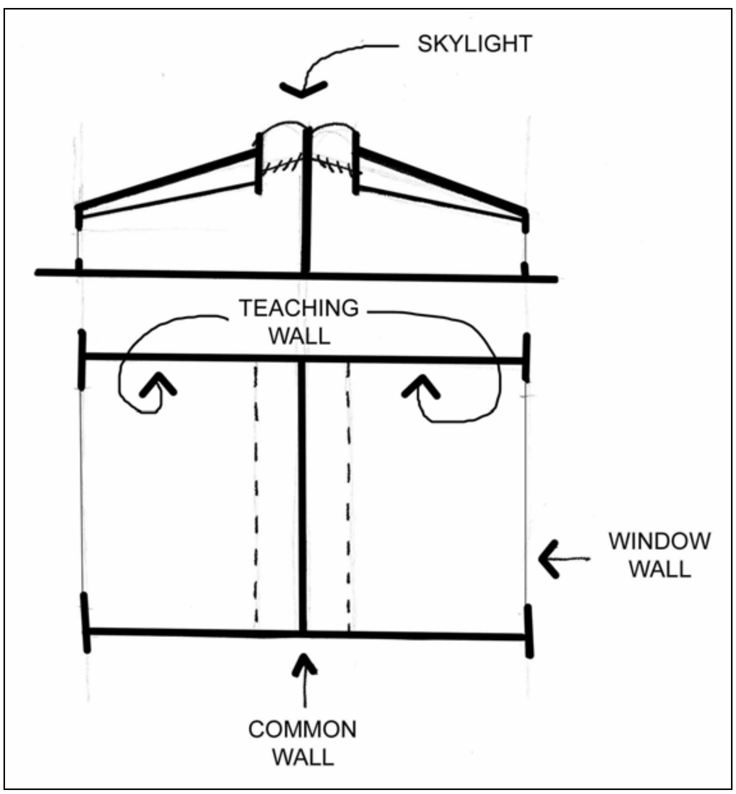


Figure 50. Section and plan of typical classrooms.

Figure 51. Exterior view of school building.

The roof is sloped away from the "spine" of the building. Therefore ceiling height varies. The common wall side is about 13' high, while the window side ceiling is 10' high.

Light Well Construction

Skylights are arranged in pairs along the "spine" of the building.

Figure 52. Twin skylights on the roof.

A gypsum board light well about 4' deep goes from the rows of skylights into the classroom space. It is painted white to allow for maximum reflectance.

Figure 53. Daylighting from the skylight.

Because of the variable activities being conducted in the classroom, eg lectures, presentations, louvers are located below the skylight to allow user controls of the amount of daylight filtering into the space. Although, based on teacher interviews, the setting of the louvers is very rarely changed.

Figure 54. Manually-controlled louvers.

Daylighting and Lighting Controls

Daylight levels on the desks typically vary from 125 fc (below the skylight) to 31 fc (6' from the window). These are enough for comfortable classroom function. Daylight from the skylight can be controlled by manually adjusting the louvers below it. Meanwhile, window daylight levels can be adjusted by drawing black-out drapes across them.

Electric lighting was also provided to supplement the daylight. There are three rows of lensed ceiling mounted luminaries, fitted with T-8 lamps and electronic ballasts. They provide an illumination of 40 to 60 fc on the desks. The switching pattern is parallel to the windows and skylights. The electric lights are automatically switched by photosensor controls as determined by light levels. But a wall switch in the room also enables the users to adjust the light manually, and disable the automatic switching feature. Many of the photosensors were observed to be covered over, during a site visit.

Figure 55. Lighting from skylight and electric lights.

Capital Cost vs. Energy Savings

The estimated savings from automatic photosensor controlled switching system is in the range of $75 to $150 per classroom per year. But because it is often disabled, the actual savings would be less than the projected amount.

9. Grocery Store B

Grocery Store B is a chain of grocery stores operating in over half the country. They also own other operations such as drugstores and quickstop stores. They have been expanding their efforts in improving the environment by adopting recycling programs, and improving their stores' energy management. They have received numerous awards for these efforts.

They built about 250 sites so far and currently have 500 jobs under contract. Among these projects are their 5th and 6th skylit stores in Southern California. This case study is based on interview with the construction manager of the grocery store.

Design and Planning

Their grocery stores are either owned, leased or on other kinds of real estate contracts. Because of this variety in ownership, site and building design control are hard to establish. They are about 47,000 SF in size. They have 24' high roof decks, and the interior ceiling is left exposed. They have gray floors, beige walls and sage-colored ceilings at 30% reflectance. Because they are self-insured, risk issues are important. All stores have sprinkler systems installed.

Their drug stores are usually owned buildings, situated on a corner lot. This ownership set-up will allow them to incorporate skylights more easily. They are about 16,000 SF in size, with 17' high metal roof decks. They have 13' high T-bar ceilings on the interiors. Often, they do not incorporate a sprinkler system within these stores.

Their quick stop stores have different formats, and are finished with T-bar ceiling systems.

Daylighting and Lighting Controls

They are currently using 5% skylight to floor ratio, with a skylight visible light transimission of 43 – 59%. They are achieving 30 fc in their stores in October at noon in LA.

A photocontrol system is set-up in only one store. All other daylit stores have the ability to turn off 25%, 50% or 75% of lights in all stores. During the energy crises last year, they had to turn off 50% of their lights and their sales performance suffered greatly.

Capital Cost vs. Energy Savings

An independent consultant conducted DOE2 analyses of their operations in the various states where they have established operations. Because of the extensive refrigeration in the stores, they find they have almost no air conditioning loads in most of their stores. They do have heat recovery, though, mostly for dehumidification purposes in pre-conditioning air.

The results indicate that all daylit stores are showing net whole building energy losses, except for their California stores. The California stores are seeing energy savings of only $2,000 per year, attributed to the presence of the skylights.

The cost of hung ceilings is about equivalent to the cost of painting the ceiling, structures and mechanical systems. People often prefer the open ceiling. They have considered tubular installations. But at three times the cost of skylights, the tubular skylight is too expensive. Meanwhile, a skylight system with a gypsum lined light well is twice the price of just the skylights. They have not considered using T-bar ceiling for the well.

Because of the cost of skylight installations, the energy savings do not contribute to the cost-effectiveness of the system. The decision to incorporate the system is left up to the regional teams. They do not believe reports that better lighting will result in an increase in sales because they have not found similar results within their operations.

Materials

Item	*Material*
Ceiling	T-bar ceiling panels
Light well	Gypsum board
Splay	Gypsum board
Skylight	Clear acrylic
Lens	None

Problems

Company executives were unhappy with the skylight installations in their prototype stores. There were glare effects caused by the skylights and the contrast in light levels made the ceiling appear darker.

10. Retail Store A – System 1

Introduction

Retail Store A is a national chain retail store with a market base built on offering trendy merchandises at low prices. They have over 1,000 stores and are present in most states, with each store approximately 125,000 SF in size. They have some superstores, which are bigger in size. At present, they have six skylit stores in the country. Each store uses a different skylight system. We will be discussing System 1 in this case study and System 2 in the succeeding one. This case study is based on interview with the construction manager of this retail store.

Design and Planning

Their stores typically have a 6’ deep plenum. They have rigid insulation on top of the built-up roofing. Because of this, they do not have to insulate the light well of the skylight.

Light Well Construction

The System 1 skylight has a 20” x 40” opening in the roof, transitioning into a 4’ x 4’ well. The vertical throat of the light well is approx. 6’-8’ high and the splayed portion approx. 4’ high. The well is vertical, finished with white reflective film. The ceiling tiles at the splay are finished with a reflective surface. The splay at the bottom can be offset from the vertical well to accommodate the ceiling grid layout.

Ceiling Tile Pattern

With the light well of 4’x4’ dimensions, alignment with ceiling tile pattern is relatively easy. Skylight splay moves in any direction to comply with the ceiling grid.

The detail below shows the skylight diagram if skylight is aligned with the ceiling grid design, resulting in equal splay dimensions.

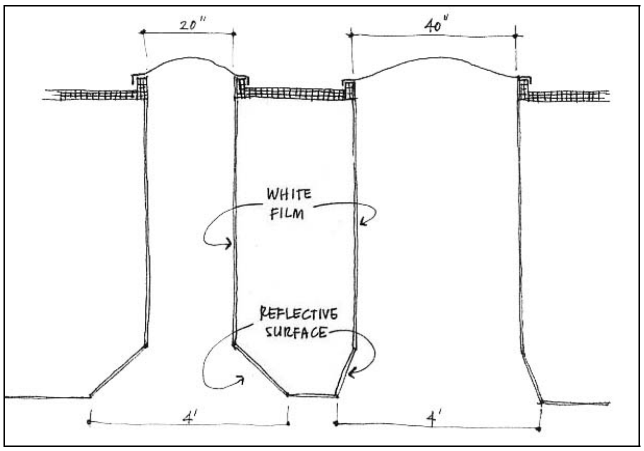


Figure 56. Section of skylight (two directions).

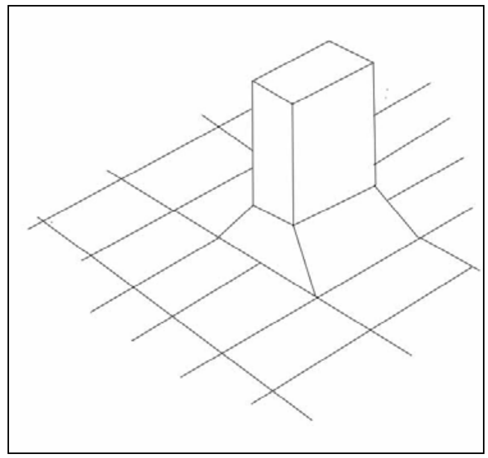


Figure 57. Skylight interaction with ceiling grid pattern.

In certain cases, the splay is offset to allow the skylight opening to match the ceiling grid pattern. The diagram below shows how this works.

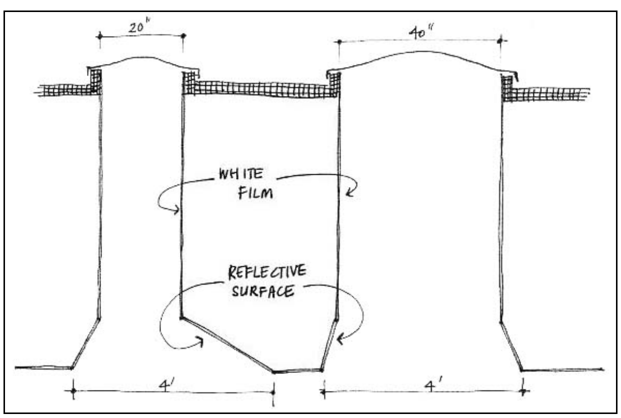


Figure 58. Section of skylight (two directions) with “adjusted” splay.

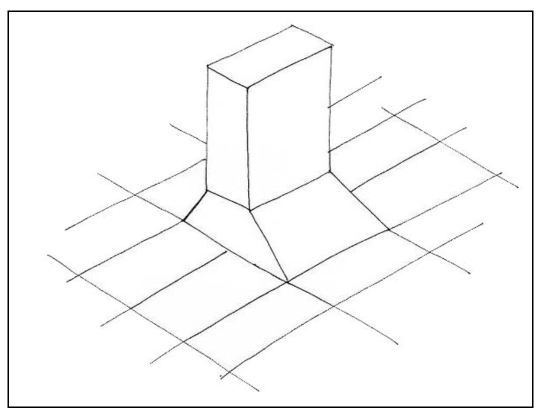


Figure 59. Skylight interaction with ceiling grid pattern.

Materials

Item	*Material*
Ceiling	2' x 4' acoustic tiles
Light well	White film
Splay	Reflective surface on ceiling tiles
Lens	None

They have also experimented with using sheetrock for the light well. But it was too heavy and required finishing and raising the costs.

Capital Cost vs. Energy Savings

Retail Store A was able to negotiate a very affordable energy rate form the utility companies in California. Because of this, cost effectiveness of the skylight system was difficult to achieve. Their financial calculations did not consider the positive sales effect of daylight within their stores.

Problems

One problem that they were worried about was within the skylight well. But so far, none of their stores have had a problem with condensation.

11. Retail Store A – System 2

Light Well Design

The CA stores used a 22" tubular skylight system. It uses a proprietary reflective tubing that allows maximum light reflection. Its flexibility allows it to easily adjust to the ceiling tile dimensions and changes in future interior layouts. The diffuser is the Optivew® High-performance Fresnel Lens that allows the outside sky to be reflected into the interior spaces, giving occupants a sense of being connected to the outdoors.

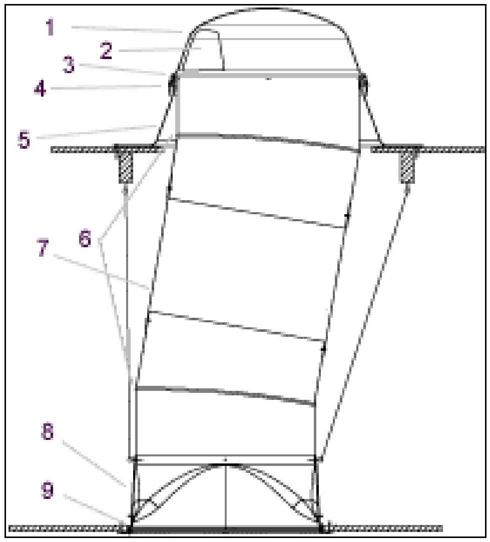


Figure 60. Section of tubular system.

(Source: Solatube International)

Building Systems Coordination

At present, Retail Store A is focusing on new and remodeled constructions. A substantial number of their construction projects are remodels. This is both for maintenance purposes and for image update. Retail Store A often has to configure the skylight to accommodate existing systems. This issue was resolved in the CA stores by using the flexible tubular skylight.

Their store planning group also tightly coordinates all systems in a uniform, attractive pattern. These include diffusers, sprinklers lights, tile patterns and the structural columns. The use of the tubular skylights allows it to change positions from the roof opening to accommodate the required ceiling grid pattern.

Though the system appears effective is resolving these construction-related issues, its small dimensions and unsplayed opening is less aesthetically pleasing than a splayed skylight system with a larger opening.

Materials

Item	*Material*
Ceiling	2’ x 4’ acoustic tiles
Light well	Spectralight® Infinity
Splay	No splay
Lens	Optiview® Fresnel lens

12. Grocery Store C

Grocery Store C is part of a company operating with different brands and many markets: they have a warehouse brand, a regular grocery store and an upscale foodstore and numerous other sister companies.

Their grocery store and the warehouse brand currently use skylights in all their new construction. They are also considering incorporating skylights in some remodels they are doing.

Their upscale brand, requiring a much nicer store image, uses t-bar ceilings in all their stores. They would consider adding skylights to this brand, if skylights can be economically combined with T-bar ceilings.

Meanwhile, a sister company will also start incorporating skylights in their operations in another state.

13. Agriculture Technology Application Center (AgTAC) Kitchen

Introduction

AgTAC was designed by the Southern California Edison to apply the latest developments in agriculture to improve productivity and competitiveness. The 16,000 SF facility is located in Tulare, California. The case study discusses a skylight system integrated with a dropped ceiling used in a kitchen within the facility. This case study is based on interview with the architect and the manufacturer.

Design and Planning

The kitchen is of a small size, and thus required the use of only one skylight, centrally located within the space. The ceiling height is 9', and finished with 2'x4' acoustic ceiling tiles on a T-bar suspension system.

Figure 61. Skylight in the kitchen.

(Source: SNS technology website: http://www.snstechnologyllc.com/kitchen.htm)

Light Well Construction

The skylight system consists of a domed skylight on top of the roof. The opening is 4'x4' in dimension. Inside the dome, a mirror assembly brings light in from the outside. A light well runs vertically down from the roof to the ceiling. The light well is about 2' to 3' long. The system does not have a splayed opening. It has an acrylic diffuser dropped 1" below the ceiling level that covers the light well opening.

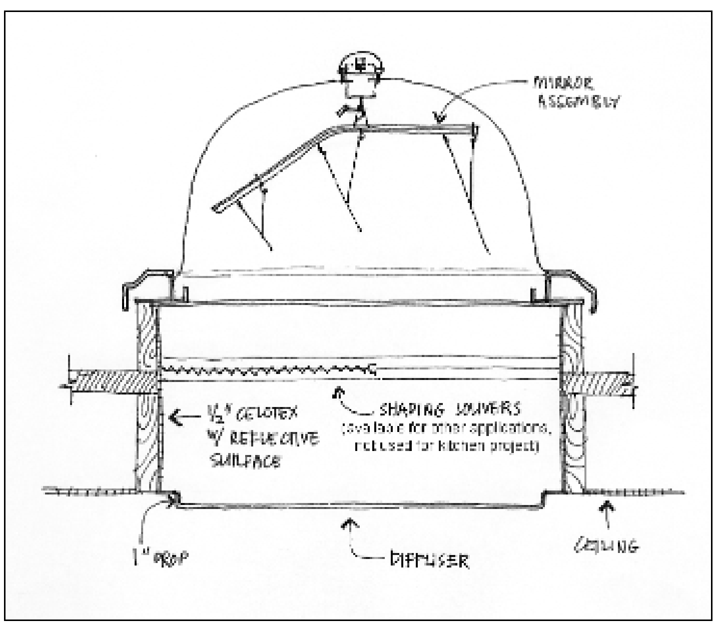


Figure 62. Skylight section.

Connectors

Because of the absence of a splayed opening, the assembly of the system is simplified. No special connectors were required in this project.

Building Systems Coordination

Because the project is the retrofit of an existing building, all building systems were already in place. Skylight system had to work around the existing utilities inside the ceiling space, but no special problems were encountered.

Ceiling Tile Pattern

The dimensions of the skylight (4'x4') and the ceiling tile (2'x4') coordinates well with each other. They did not require special tile sizes or irregularly cut tiles on the job site.

Daylighting and Lighting Controls

No special lighting schemes or control systems were implemented in this project to accommodating new daylighting strategy. In other applications of the skylight system, a louver system can be incorporated in the light well to modulate the light levels remotely.

Fire Code

No sprinkler heads were required to be installed on the inside of the light well.

Materials

Item	*Material*
Ceiling	2' x 4' acoustic tiles
Light well	Polyiso insulation "celotex" with reflective surface
Splay	None
Skylight	Clear acrylic with mirror assembly
Lens	Acrylic lens (milky-white color)

14. Grocery Store D

Grocery Store C is a smaller grocery store chain operating numerous stores across the west coast. These include different brand names: 3 supermarket brands, and a warehouse format brand. This case study is based on site visit.

Figure 66: Ceiling view with skylight wells and lighting layout

Planning and Design

Sprinklers are spaced 8' apart, with ceilings at 14' height. The electric light layout runs parallel along the length of the skylight and spaced every 10' apart. Some sprinklers are also located within skylight wells.

Light Well Construction

The skylight is 4' x 20' in dimension made up of multiple unit skylights. It has an 8' high light well, made up of a 4' throat height and a 4' splay height. The light well opening in the ceiling is 8' x 28'.

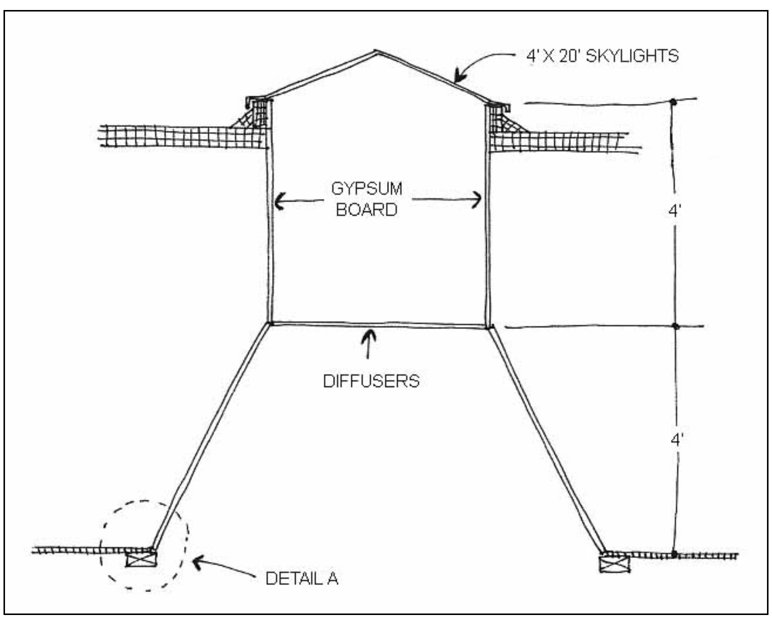


Figure 63. Skylight section.

Connectors

The splay is constructed of gypsum board. A t-bar suspension angle is connected to the edge of the gypsum construction to support the ceiling. The connection between the splay and the ceiling is covered up with wood trim.

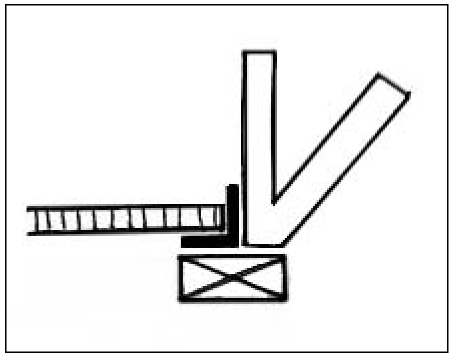


Figure 64. Detail A, splay and ceiling connection.

Materials

Item	*Material*
Ceiling	T-bar
Light well	Gypsum board
Splay	Gypsum board
Skylight	Clear prismatic acrylic lens
Lens	Clear acrylic lens

15. American Honda NW Regional Facility

Introduction

The American Honda NW Regional Facility is located in Gresham, OR. It houses a warehouse, training center and office facilities in 212,888 SF of space. It is a LEED certified building with a GOLD rating, designed by MacKensie Architects. It used a combination of green design features to achieve this rating, including rainwater collection, gray water recycling, using building materials of recycled and recyclable products, and daylighting. This case study is based on interview with the architect.

Planning and Design

Figure 65. Honda facility with the skylights on the rooftop.

(Source: Honda Corporation)

The office building is a one-story structure, with a central courtyard and a warehouse abutting the south wall of the office building. The office space is an open plan with enclosed conference rooms.

The ceiling is 12' high. Windows 3' to 12' provide sidelighting. The east and west windows have louvered exterior sunshades and interior lightshelves. The clerestory windows are of clear glass and the vision windows are tinted glass. Windows on the north side do not have sunshades or louvers.

Skylight Design

The interior space of the office and showroom has skylights with diffusing domes. Each skylight is rectangular, approximately 7' x 25' in dimension and spaced at every 20 ft.

Conference rooms have clerestory windows to “borrow” daylight from the outside office spaces.

The warehouse is 140,000 SF and has 22' high ceilings. It uses 120 smoke venting skylights and has twice the area required by code for smoke exhausting.

Figure 66. Showroom with skylights.

(Source: Waste Reduction Action Information Network (WRAIN)

Light Well Construction

The light well is a vertical 6' high without any splay. At some places where the ceiling height is 12', the light well height is 9'. The material used is gypsum board painted white inside. The bottom of the light well does not have any diffuser.

Connectors

At the junction where the gypsum light well meets with the T-bar ceiling grid, a metal stud is wrapped with gypsum board at that point and there is a difference of 1" between the gypsum and the ceiling panel that gives it an edge detail.

Building Systems Coordination

The use of skylights in the office affected the duct and air diffuser layout, but they were still able to achieve an efficient layout. Cooling load was probably higher due to the skylights and windows.

Ceiling Tile Pattern

The ceiling height ranges from 12' to 15' and is made of 2' x 2' acoustical tile panels.

Daylighting and Lighting Controls

The office lights are on dimming ballasts and are controlled by photocell sensors. The space is subdivided into 4 photo-controlled zones: the interior as one, and the three perimeter zones as individual zones (south is not daylit). There are no override features for the lights which are controlled by a central unit.

The conference rooms use occupancy controls, but do not need photocontrols because of insufficient daylight.

The warehouse space uses a hi/low stepped HID fixtures with 50% and 100% levels. It is controlled by a combination of occupancy sensors and photocell sensors. Occupancy sensors at the end of each aisle detect the presence of people and will bring the light levels up from 50% to 100%. But if there is sufficient daylight, the photocell sensors prevent that from happening. Because it uses high pressure sodium lamps, they do not let the lights turn completely off. The central controls also make sure that the lamps operate at 100% levels for at least 15 minute each day for optimum performance.

Figure 67. Warehouse with HPS lighting
(Source: Waste Reduction Action Information Network (WRAIN))

Fire Code

The fire code required the building to have sprinklers in the light well. Each skylight has two sprinklers located within the light well

Materials

Item	*Material*
Ceiling	T-bar, 2' x 2'
Light well	Gypsum board
Splay	None
Skylight	Translucent lens
Lens	None

Capital Cost vs. Energy Savings

75% of the office can be fully daylit[23], while 80% of the warehouse can be fully daylit. When the docking doors of the warehouse are open, 100% of the space is fully daylit.

Models run by energy consultants show that the lighting system used 46% less energy than a baseline model. Meanwhile, energy cost savings are at 42% less than baseline, but not all savings is attributed to lighting only. Energy models assumed reduced cooling load due to daylight controls, but system was sized

[23] Fully daylit is when at least 50% of the electric lights could be turned off under peak daylight conditions.

according to full lighting loads on top of full solar heat gains (due to additional fenestration).

The whole project cost about $22M, which is about $1.5 to $2M more than a conventional project. It has a 7 to 11 year payback on the green technology investments, but Honda is planning to occupy the building for 40 to 50 years. But because of these green initiatives, Honda NorthWest has become Honda's showpiece of green technology.

Problems

Commissioning would ensure that all lighting controls work properly. The benefits of daylighting are heavily dependent upon the proper operations of this system.

16. US Postal Service Center – Nashua, NH

Design and Planning

The USPS Distribution and Delivery Center in Nashua, New Hampshire is a 25,800 SF space with six skylights installed in its central sorting room. The ceiling height within the sorting room is 17' and is finished with 2'x2' ceiling tiles. It was the third skylit facility built for the USPS by this architect. This case study is based on interview with the architect.

Figure 68. Triangular skylights on the rooftop.

(*Source: NYSERDA)*

Design of the system is complicated by security and safety concerns. Instead of the usual bubble design installed in other facilities, a steep pitched skylight was designed to accommodate the snowy New Hampshire winter.

Extensive west-facing glass block windows complemented the skylights. This 15' high, 60' long expanse of glass is flanked on either side by 4' high clerestory windows.

Figure 69. Glass block windows.

Figure 70. Skylight over sorting area.

Light Well Construction

The six skylights are made of double-walled extruded polycarbonate glazing material. The skylights are 22' above the floor and set on a 60'x45' grid. It is also frosted to diffuse the sunlight and soften cast shadows. The glazing has a light blue tint to give a hint of sky even on cloudy days. It is inclined at a 45˚angle to minimize snow accumulation during winter. They opening is 11'x15' in size. Though smaller sized skylights would provide better light distribution, they will be more likely to be covered in snow during winter and reduce the minimal winter sunlight.

The vertical light well is 5' deep and made of white painted gypsum board. 6" wide soffit frames the opening in the ceiling.

Figure 71. Light well.

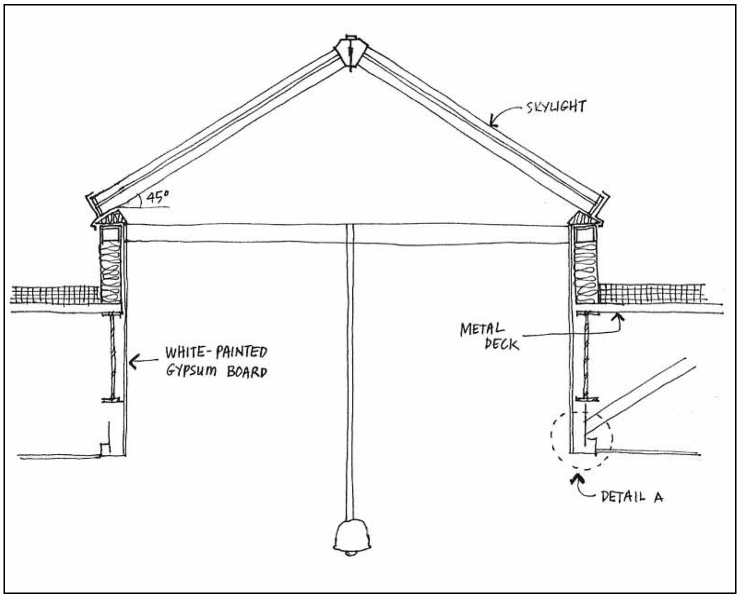


Figure 72. Section of skylight.

Ceiling Tile Pattern

The soffit around in the skylight skylight opening is 6" wide. It adds 1' to the dimensions of the skylight each way and makes the final dimension, 12'x16' match the ceiling tile pattern.

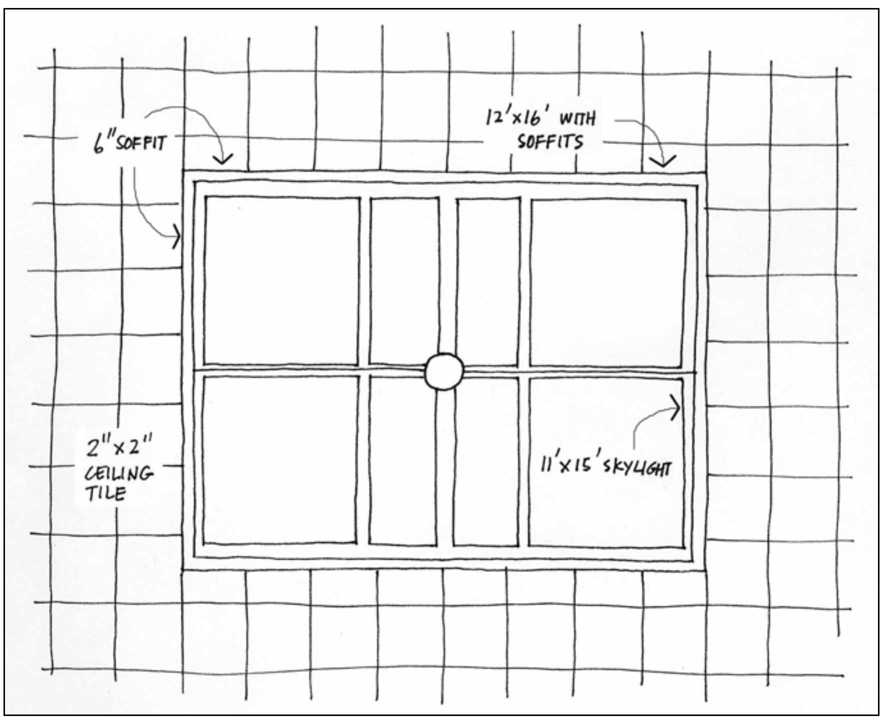


Figure 73. Ceiling tile pattern.

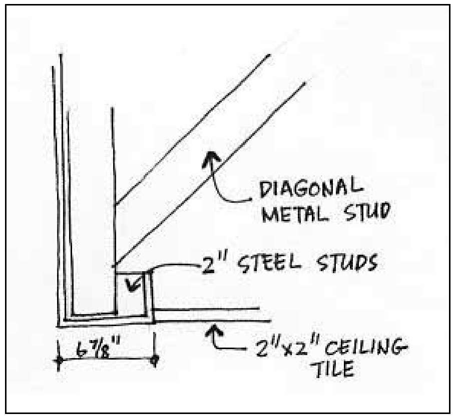


Figure 74. Detail A, soffit detail in ceiling.

Daylighting and Lighting Controls

An electric pendant light hangs from the middle of the skylight. The electric lights provided are high-intensity metal halide lamps. Therefore, fewer lamps were required in the space. The switching is also laid out in such a way that they can be switched on and off according to light levels when entering the room.

Light levels are controlled by photosensors. They are located facing up into the light well. If sufficient daylight is entering the light well, electric lights will be automatically switched off. They typically turn off at 10:30 am and stay off for the rest of the day. This system saves from 40 to 100kWh per day, depending and the season and weather. It reduces the building’s peak demand by up to 12kW.

Fire Code

Sprinkler heads are located in the light well for fire protection.

Materials

Item	*Material*
Ceiling	2’ x 2’ acoustic tiles
Light well	White-painted gypsum board
Skylight	Double wall polycarbonate pyramid
Splay	None
Lens	none

Problems

The facility experienced problems with leakage from the skylight flashing a few years ago. The problem had been resolved and it has been trouble-free since.

Condensation was a possible problem and measures were taken to avoid it. The metal frame supporting the skylight was packed with insulation, and a condensation gutter was designed into the base of the frame to catch moisture.

17. Retail Store B

Retail Store C is a national corporation with a variety of department store brands and have had prior experience with skylights in their buildings and some of their experiences with skylights are described below. They are once again considering them as part of a 'green' building package. According to the lighting designer for these stores, roof top curbs have been very problematic and they would like to avoid it as much as possible in future.

Any penetrations like skylights have always needed to be coordinated with the structural steel spacing. At present, they are experimenting with exposed ceilings for an "edgy" look in some departments. Their choice of ceiling type has strictly been based on aesthetic issues. They often use gyp board ceilings for a really polished look.

They are concerned that adding skylights would not contribute in changing the "appearance" of the stores. A major concern for them is leaks through skylights. Another concern for them is the color rendition issue with lighting and are trying to figure out how to go with lower lighting energy. However, they are interested to see results from skylights with more sales, more traffic, customer satisfaction and lower returns on items.

18. Retail Store C

This retail store typically has used skylights without T-bar ceilings in most of their stores. For one particular store, they have installed skylights with T-bar ceilings. This was a retrofit project, which had existing T-bar ceilings. The spacing of the skylight was based on the already existing structure. There are 34 skylights and each one is 4'x4' in dimension spaced every 20' apart. The total height of the ceiling is approximately 12'. The light well is 4' in height and consists of a vertical throat that comes down straight to the T-bar ceiling. The throat is made of prefabricated ½" sheet metal with insulation with a reflective material celotec in the inside surface of the light well. They did not use acoustical tile or gypsum board as the light well material because they wanted good light diffusion and preferred using the sheet metal with reflective material. 90% of the adjustments to the existing ceiling components was made with no problems. They did not have any problems with sprinkler spacing as some of the sprinklers were just placed in the light well area.

The skylight designer recommends the use of 4'x4' skylights every 20'-30' spacing in order to maintain the 100fc of light levels in the space. Integrating skylights with dropped ceilings has been a much better experience for them.

According to the designer, ideally the light well height should not be more than 10’ in height.

19. University of Rhode Island

Building Description

The Rhode Island University in Providence, RI has included daylight and top lighting in all its new campus facilities since the late 1980's. The first facility in the series was the Health, Physical Education, and Athletic Complex. The facility was well daylit with translucent fiberglass sandwich panel skylights. With high occupants and student's satisfaction with the indoor lighting quality of the Complex, Rhode Island University has since used the same skylighting material and top lighting strategy in three more buildings: the University Library, and the Dinning Services Administration Building and Warehouse, and the new Business School building.

The Dinning Services Warehouse and Administration Building, houses 8,500 SF of office space. Daylighting is clearly emphasized as the main lighting strategy throughout the building. The office space of this area has skylights with T-bar ceilings, described below.

Skylight Details

The office spaces were mainly daylit with three large pyramid-shaped skylights with 15’x15’ dimensions and with a total floor area of 900 SF (see Figure 86). The skylight is fixed on to the roof with metal connectors and is 3’ in height. This resulted in a 10.5% of skylight to floor area ratio for the office space section of the facility. All skylights used are translucent fiberglass panel skylights. The U-factor for the skylights is 0.24, shading coefficient of 0.30, and a 30% light transmission.

Figure 75: Pyramidal shaped skylight over the office space

Light Well Design

The light well of the skylight spans 15'x15'. The light well is made of gypsum board and is 4' in height. The junction where the light well meets the ceiling is lined by a mahogany wood trim to conceal the joinery between the acoustical tile panels and the gypsum board (see Figure 87).

Figure 76: Edge condition between gypsum board light well and ceiling

Design Issues

The ceiling height is 10' with the roof another 4' above the ceiling. The architect had no problems in the installation of the skylight and integrating it with other components. The skylights were custom designed by the manufacturer and since the building was not a retrofit, they did not have any spacing issues with the structural elements and designed the size of the skylights based on the structural design. The placement of sprinklers was not an issue in the design and were placed along the sides of the light well wherever required. The architect has continued to use gypsum board as the material for the light well for other design projects as it is easy to detail and gives a clean appearance aesthetically.

Materials

Item	*Material*
Skylight	Translucent fiberglass panel
Light well	Gypsum board
Splay	None
Connectors	None
Bottom Diffuser	None

20. Solatube International, Inc. Office Space

Planning and Design

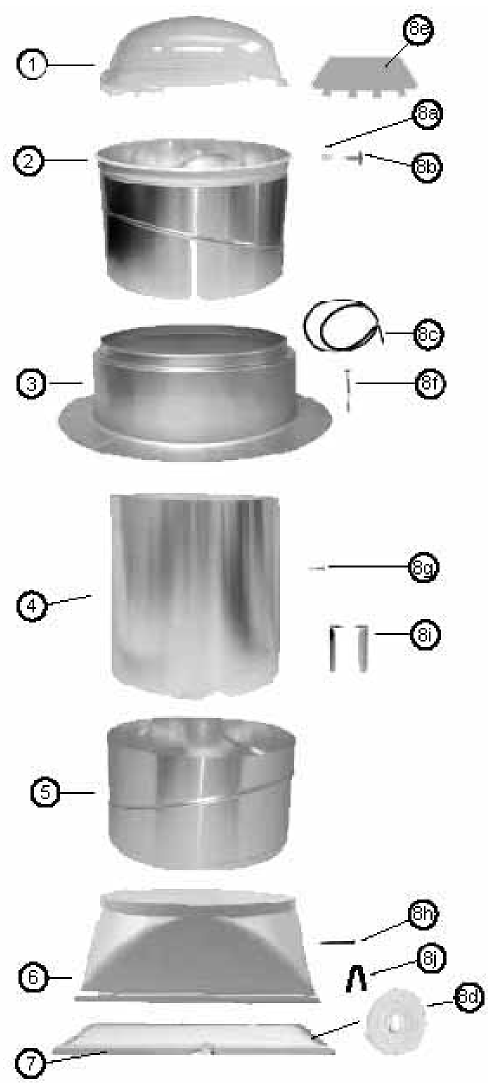
Figure 77. Solatube application in an office.

Figure 78. Solatube application in a boardroom.

Light Well Construction

The Solatube skylight is 22” in diameter and made of acrylic bubble 0.125” thick. It has visible light transmission of 92%. A dome ring connects the dome to the Spectralight Infinity tubing. The ring also incorporates a condensation gutter to prevent water leakage into the space.

The tubing / light well is made of 0.015” thick aluminum sheet. It is finished with a reflective film, protected by a PET coating for added durability, to maximize daylight reflectance inside the tube. The small diameter of the tubing allows the light well to easily fit between structural and mechanical systems within the plenum. Each extension tube is 24” long and can be connected to more tubes for a total length of 40’. The angle sections also allow the light well to change directions to adapt to the ceiling grid pattern. The transition box is made of white acrylic and is covered by a lighting diffuser panel. The diffuser panel is of a dimension that fits T-bar suspension ceiling systems.



1. Duradome
2. Top Tube assembly
    a. Dome ring
    b. Spectralight Delta Top Tube
3. Roof flashing
4. Spectralight Infinity Extension Tube
5. Spectralight Delta Bottom Tube
6. Transition Box
7. Diffuser
8. Seal and Fastener kit
    a. Dome spacers
    b. Dome screws
    c. Dome seal
    d. Diffuser seal
    e. Light Intercepting Transfer Device
    f. Flashing screw
    g. Tube screw
    h. Drywall mounting screw
    i. Foil tape
    j. Transition hold down clip

Figure 79. Solatube components.

Building Systems Coordination

The angle adaptors and small dimension of the Solatube tubing allows it to navigate between building systems in the ceiling space.

Ceiling Tile Pattern

Diffuser dimension of the Solatube system matches the dimension of the ceiling tiles. The angle adaptors also allow the light well to adjust its location relative to the tile pattern.

Figure 80. Solatube light well in ceiling space.

Materials

Item	*Material*
Ceiling	2' x 4' acoustic tiles
Light well	Spectralight® Infinity
Splay	No splay
Lens	Optiview® Fresnel lens

Summary of Case Studies

The case studies discussed here include retail stores, grocery stores, educational facilities, and office spaces.

Collecting these case studies helped us determine typical space dimensions for these building types and helped us identify the challenges for the designer. They also helped us evaluate the effectiveness of different solutions used by each project to solve similar problems.

Space Planning and Design

These buildings used skylights to provide general ambient lighting. They are often located without consideration of its relation to the space function below them. One exception is Grocery Store A and C where they were carefully positioned to provide lighting for the aisle spaces. The primary motivation for their spacing is generally their interaction with the structural grid or other building systems.

Ceiling heights range from 9' to 16' in height. It plays a role in determining the splay dimensions of the skylights and their spacing. These factors contribute to the amount and quality of light that will be distributed in the space.

Plenum heights vary from 6' to 12'. This space consists of the structural, mechanical and fire protection systems.

Light Well Construction

The smallest skylight system we have evaluated was the Solatube system, which is only 22" on each side. Conventional skylights units have larger dimensions, ranging from 2' x 4' to 11' x 14'.

Light well construction is also differentiated by the type of light well installed. Some skylights have a vertical light well, in which the dimension remains constant from the skylight opening to the ceiling opening, such as those used for Oakridge High School, the AgTAC kitchen and one of the William + Paddon office skylights. Others incorporate a splayed opening for better light distribution. The smallest dimension seen in these case studies is 3'x5', while the largest is 14'x14'. In most cases, the opening is sized (in multiples of 2' or 4') to correspond to the ceiling tile dimensions to match the tile pattern. But other projects, such as Grocery Store A and Olive Ranch have different size openings that resulted in irregular tile sizes and problematic installation.

Light well heights vary according (2' to 13') to the plenum height required of the occupancy. It is measured from the skylight opening to the ceiling opening, including the splay. Splay heights vary from 2' to 5'. Some splays are designed to be of a specific inclination for optimum light distribution, such as a 45° angle for the William + Paddon or the CSAA offices.

Splay Construction and Connectors

These typically range from 45 degree to 60 degree angles. Two types of splay material are typically used in the case studies.

Ceiling Tiles and T-bar system

Splays were constructed using different materials. Some splays used a ceiling tile and a t-bar suspension system. This type of construction required complicated planning of the splay tile pattern. More detailed design of the connectors is also required. The more complicated ones are the connector between the ceiling and the splay, the connector between the splay and the throat and the diagonal members. Connectors are made from standard t-bar ceiling suspension system elements, such as angles, runners, t-sections and corner sections. Occasionally, they had to be bent to accommodate different angles for connecting diagonal elements in the splay. An advantage of using this construction system is that it can be completed without finishing or painting the surface.

One disadvantage is that more pieces, both the connectors and the tiles, have to be cut and bent on-site. This can lead to less than perfect workmanship, as can be seen in photos of Grocery Store A.

Gypsum Board Construction

Gypsum board splays resulted in the most seamless finish. They avoided the problems with connectors. But they are also heavier, required extensive finishing and painting work, and thus, have a higher installation cost.

Building Systems Coordination

Though coordination is generally a problem for all projects, it is especially difficult for remodeled projects. Resolution of building systems is often accomplished by:

Using flexible light wells, such as tubular wells:

This solution allows the light well to navigate around obstacles within the plenum. It requires less coordination work during the design stage. The downside of this is that tubular skylight systems are of a smaller dimension and do not have a splayed opening. Designers and decision makers have expressed a preference for bigger and splayed conventional skylights for aesthetic reasons and for reducing the costs associated with adding more penetrations through the roof.

Prioritizing skylight placements over systems placements:

Grocery Store A designed the skylight first before other (except for structural) building systems. This allowed them to design the space for maximum daylighting efficiency, rather than having daylighting as an afterthought when all other elements have been determined.

Using the splay to adjust opening location:

Light well splays are another element used to adjust the light well. Due to the presence of systems within the plenum, the skylight openings cannot always be directly above the light well opening in the ceiling. They have resolved this by using the splay to move the opening, resulting in certain splays being asymmetrical, moving in either (or both) directions to match the ceiling pattern.

Tradesmen coordination:

More commonly, this issue was resolved by having the project consultants communicate during the design development process to ensure that their design components do not intersect each other.

Ceiling Tile Pattern

Most of the systems were designed with the light well opening dimension that is a multiple of the ceiling tile size. This allows them to match the ceiling pattern without having irregular-sized pieces breaking up the uniformity of their ceiling design.

Daylighting and Lighting

Louvers

For retail and grocery stores, space functions are constant. Therefore, a constant light level can be maintained.

But other applications, such as educational facilities, often require a higher light level for writing or reading, and lower light levels for audio-visual presentations. These facilities incorporate louvers within the light well to control the amount of light filtering through. The louvers can be adjusted by a manual control within the space or by remote control. User feedback had indicated that manually controlled louvers are awkward to handle and discourage their use.

Electric Lighting Controls

Luminaires typically used in the systems studied included almost all types: recessed, surface mounted and suspended, fluorescent and HID. Luminaires were never placed inside a well, although in a few cases they were suspended below the well. Most lighting systems included automatic photosensors and the photosensors were often located up in one light well for the whole building.

Codes

For fire extinguishing requirements, sprinklers are often a requirement within the light well. Seismic issues are usually solved with T-bar wire systems, with some problems that might occur in heavy construction of light well involving gypsum board.

Materials

Light Well

Light wells were constructed using gypsum boards, foam boards, polyisocyanurate insulation and acoustical tile panels. Gypsum boards were generally finished with white paint, while acoustical tile panels required no finished paint, due to their high reflective surface. Other materials were surfaced with a reflective film for better light distribution.

Light Diffusers

Diffusers were clear acrylic prismatic lenses. Lenses are often flat, but some cases used lenses that are inverted pyramid shapes. They are often located in the throat, but for skylight systems without splay, they are located on a level with the ceiling.

Further Research

Finally some of the elements of further research area include the essential details/parts to work out. These are:

1) Pivoting connection from curb to throat structure
2) Adjustable (in height and angle) hanger for frame at top of splay
3) Materials options for surface of throat.
4) Frame section at top of splay.
5) Frame section at bottom of splay.
6) Infill options for splay sides.
7) Devices for light control and distribution.
8) Determination of a constrained range of geometries and sizes

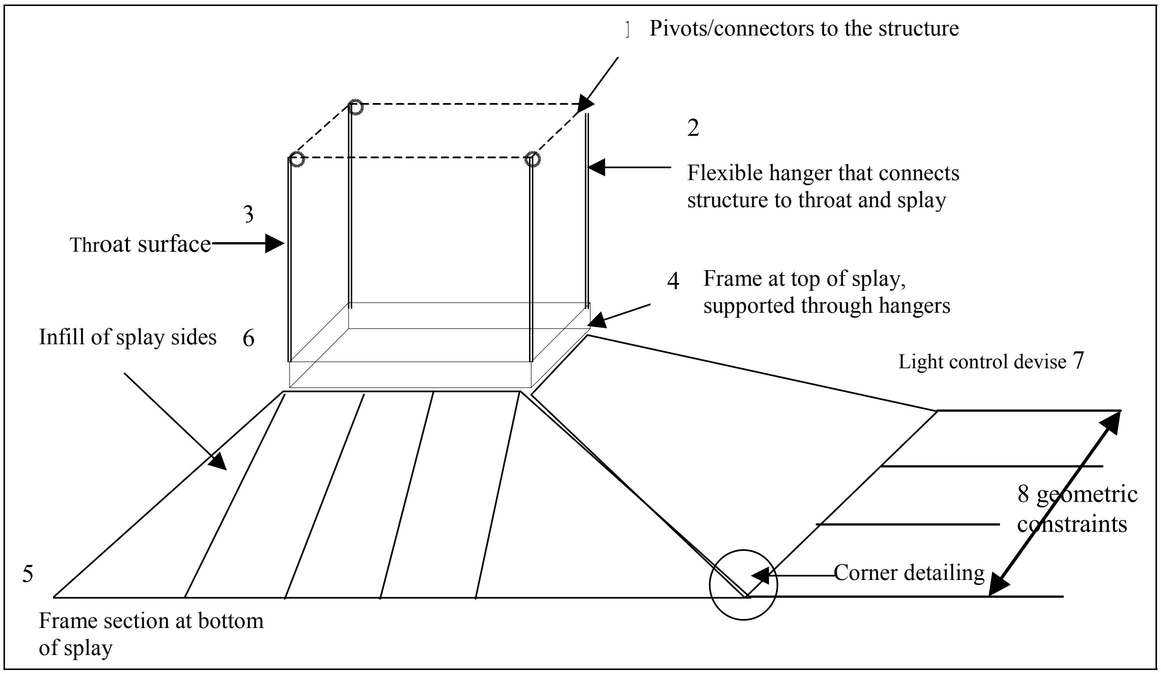


Figure 81: Connection details of a light well with a readily adjustable throat

REFERENCES

1. California Building Standards Commission. International Conference of Building Officials. *2001 California Building Code, California Code of Regulations Title 24, Part 2, Volume 1.* Based on Uniform Building Code.
2. California Building Standards Commission. International Conference of Building Officials. *2001 California Fire Code, California Code of Regulations.* Title 24, Part 9. Based on 2000 Uniform Fire Code.
3. Underwriters Laboratory Inc. 2003. *UL- 793: Standard for Safety for Automatically Operated Roof Vents for Smoke and Heat*. Available from world wide web: (www.ul.com).
4. ASTM (American Society for Testing and Materials) International. 1996-2003. *ASTM-E1264-98- Standard Classification for Acoustical Ceiling Products, American Society for Testing and Materials*. Available from world wide web: (www.astm.org).
5. ASTM (American Society for Testing and Materials) International. 1996-2003. *ASTM E-108-Standard Test Methods for Fire Tests of Roof Coverings.* Available from world wide web: (www.astm.org.)
6. National Roofing Contractors Association. *The NRCA Roofing and Waterproofing Manual,* Fifth Edition, Volume 2.
7. California Department of General Services. Division of the State Architect. 2001. *Interpretation of Regulations Document, based on California Building Code.* Section 2501A.5, 2001.
8. California Energy Commission. *2005 Building Energy Efficiency Standards for Residential and Nonresidential Buildings*, Draft 3, February 2003, P400-03-001D3.
9. National Fire Protection Agency. 2000. *Fire Prevention Code, 2000*.
10. Armstrong ceiling systems. 2002. *Architect's reference for ceiling and suspension systems*.
11. BPB 'Celotex'. 2002. *Architectural Guide for Acoustical Ceilings Systems and Accessories*. Also available from world wide web: (http://www.bmp-group.com).
12. Acoustical Ceiling Products (ACP). *Acoustical Ceiling Solutions Catalog,* 2002.
13. USG Ceiling Systems. *Ceiling Systems, Cross Reference Guide CSI-9*, 2002/2003 catalog. Also available from world wide web: (http://www.usg.com).
14. Ecophon Acoutical Ceilings. *Acoustic Ceiling Product Catalog.* Available from world wide web: (www.ecophon.com).

15. Solatube International Inc. *Commercial Application*. Available from world wide web: (www.solatube.com).

16. www.snstechnology.com

17. Acoustical surfaces Inc. *Ceilings Catalog*. Available from world wide web: (www.acousticalsurfaces.com).

18. Heschong Mahone Group, (HMG). 1999. Daylighting in Schools: An Investigation into the Relationship between Daylighting and Human Performance, Pacific Gas & Electric, 1999

19. Heschong Mahone Group, (HMG). 1999. S*kylighting and Retail Sales*, Pacific Gas & Electric, 1999.

20. Energy Design Resources. *Skylighting Guidelines,* a web-based publication on skylighting design.

21. Polyisocyanurate Insulation Manufacturers Association (PIMA). *Technical Bulletin 103*. Available world wide web: (http://www.pima.org/tbull103.html).

22. Expanded Polystyrene Association of South Africa (EPSASA). "The whole truth about expanded polystyrene”. Available from world wide web: (http://www.epsasa.co.za/documents/truth_about_ep.doc).

Appendix. A - Seismic Bracing for T-bar Ceilings

This section shows figures that describe some details required for specifying seismic conditions for metal T-bar suspension systems. The source for the following figures is: California Department of General Services. Division of the State Architect. 2001. *Interpretation of Regulations Document, based on California Building Code.* Section 2501A.5, 2001.

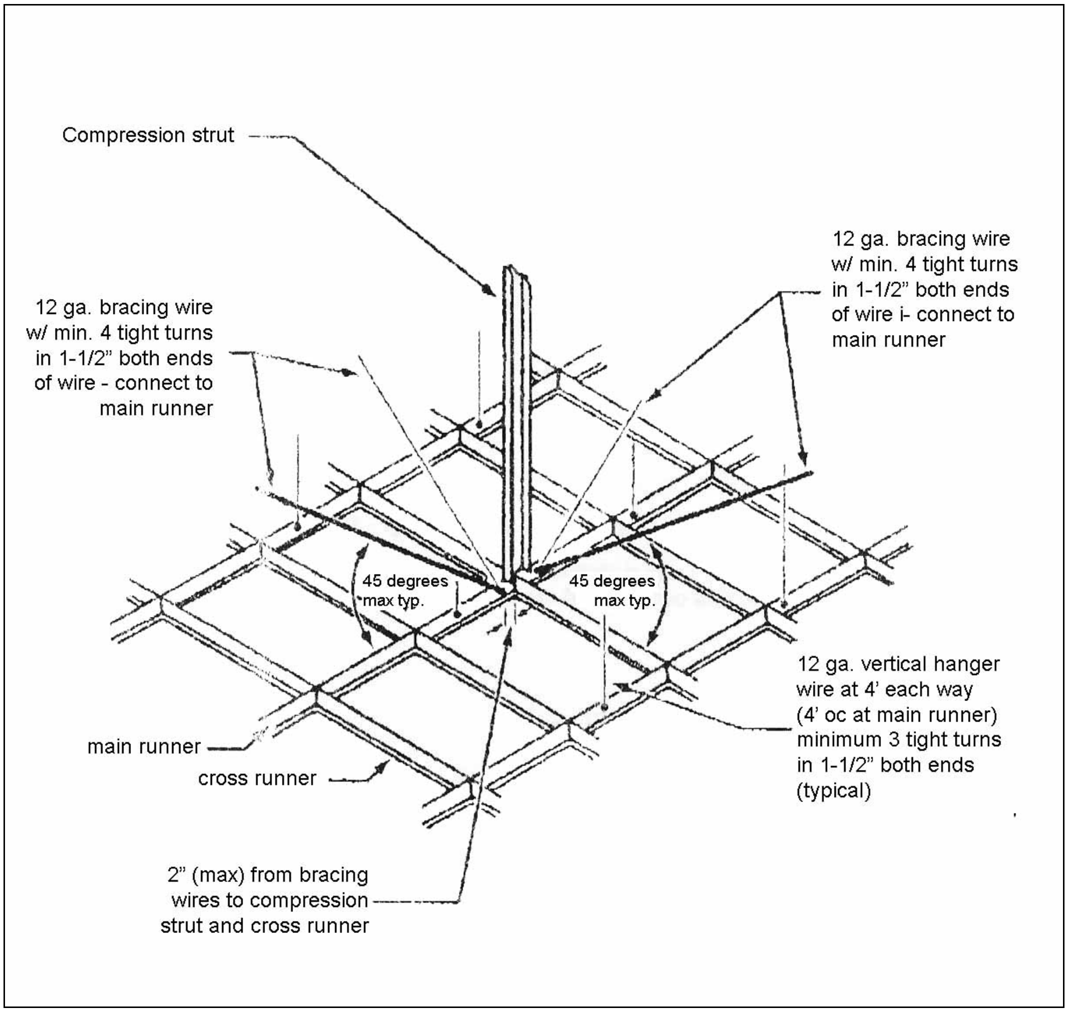


Figure 82. Suspended Ceiling Bracing

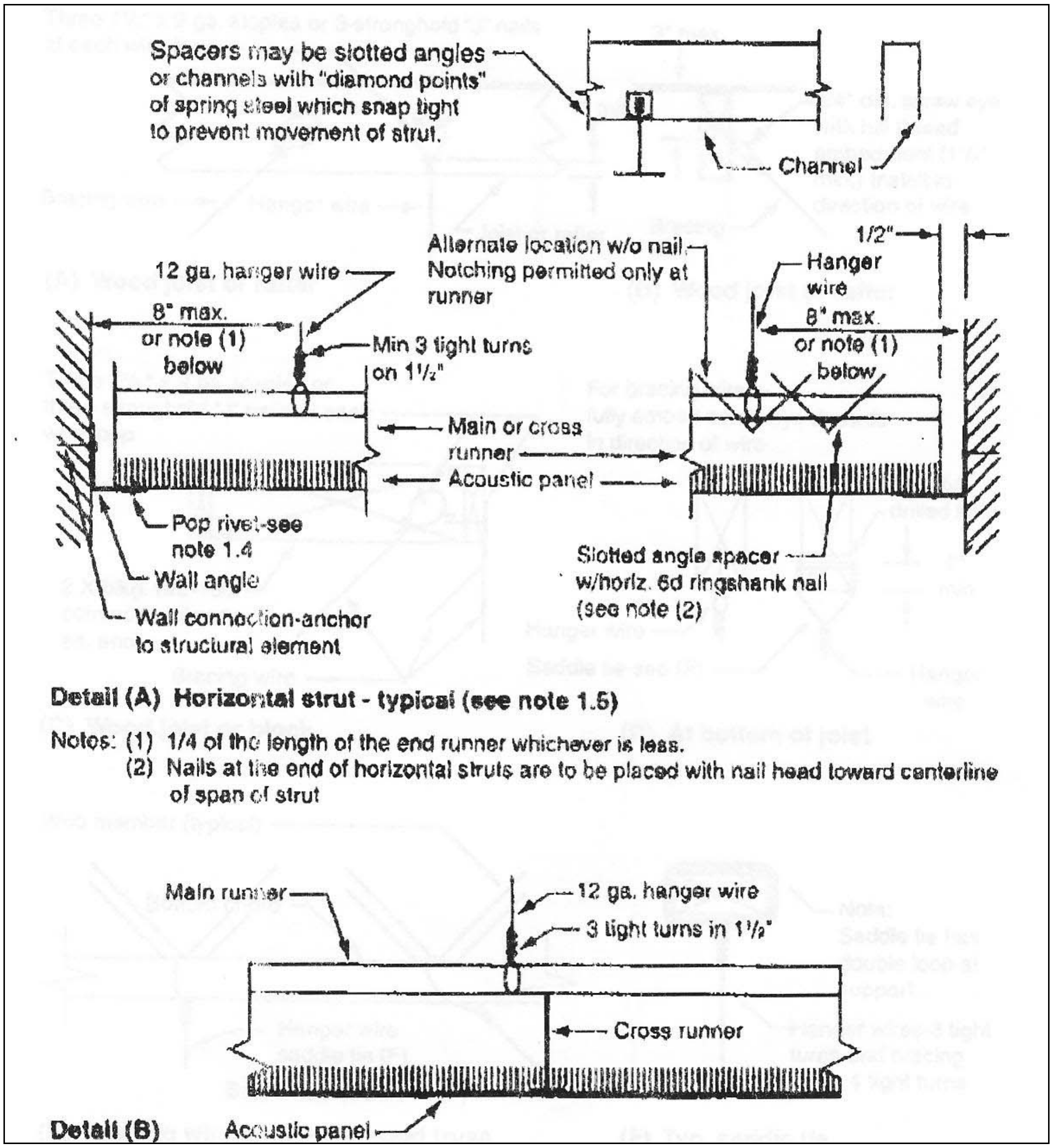


Figure 83. Hanger connection to grid

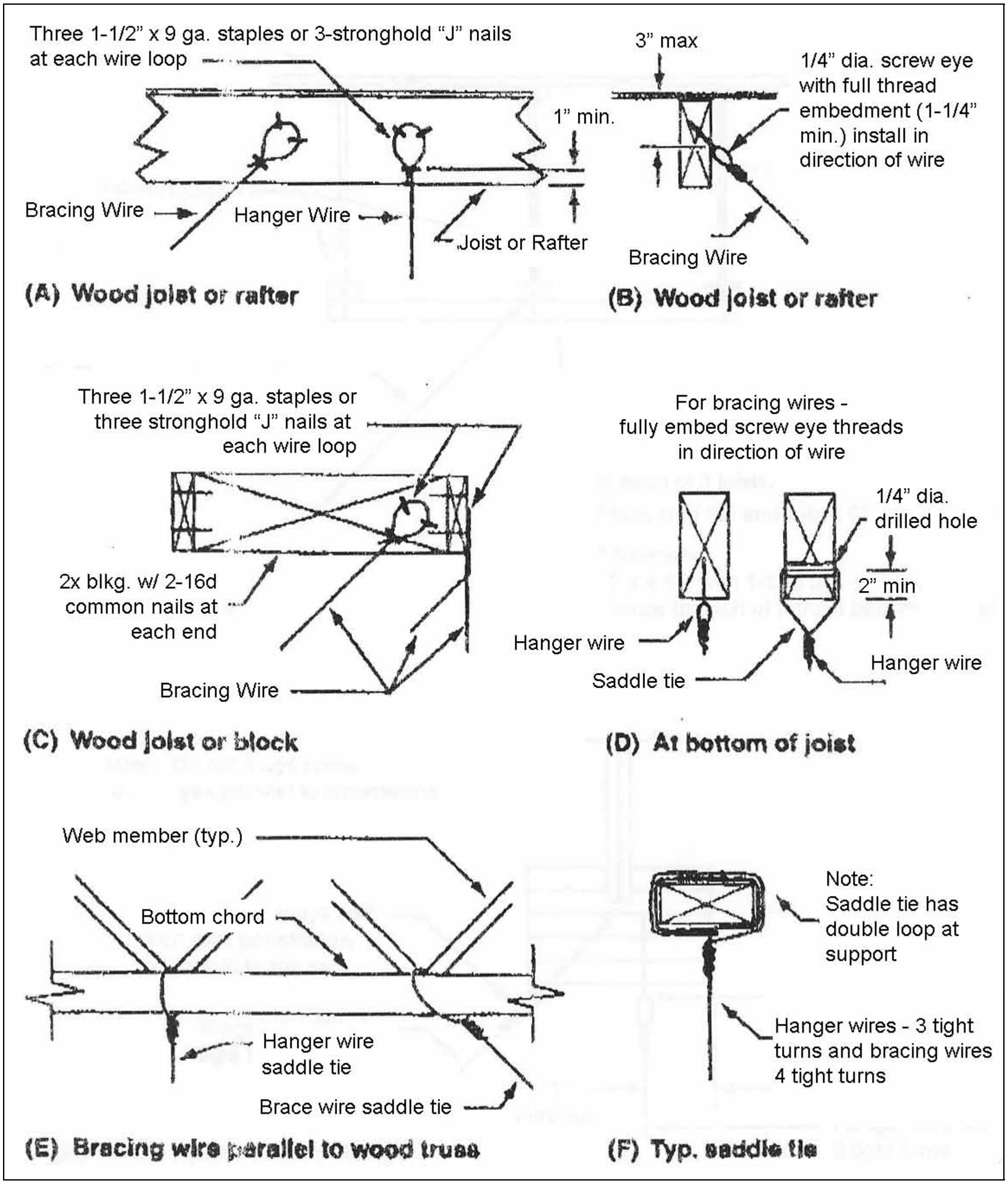


Figure 84. Hanger connection to wood frame

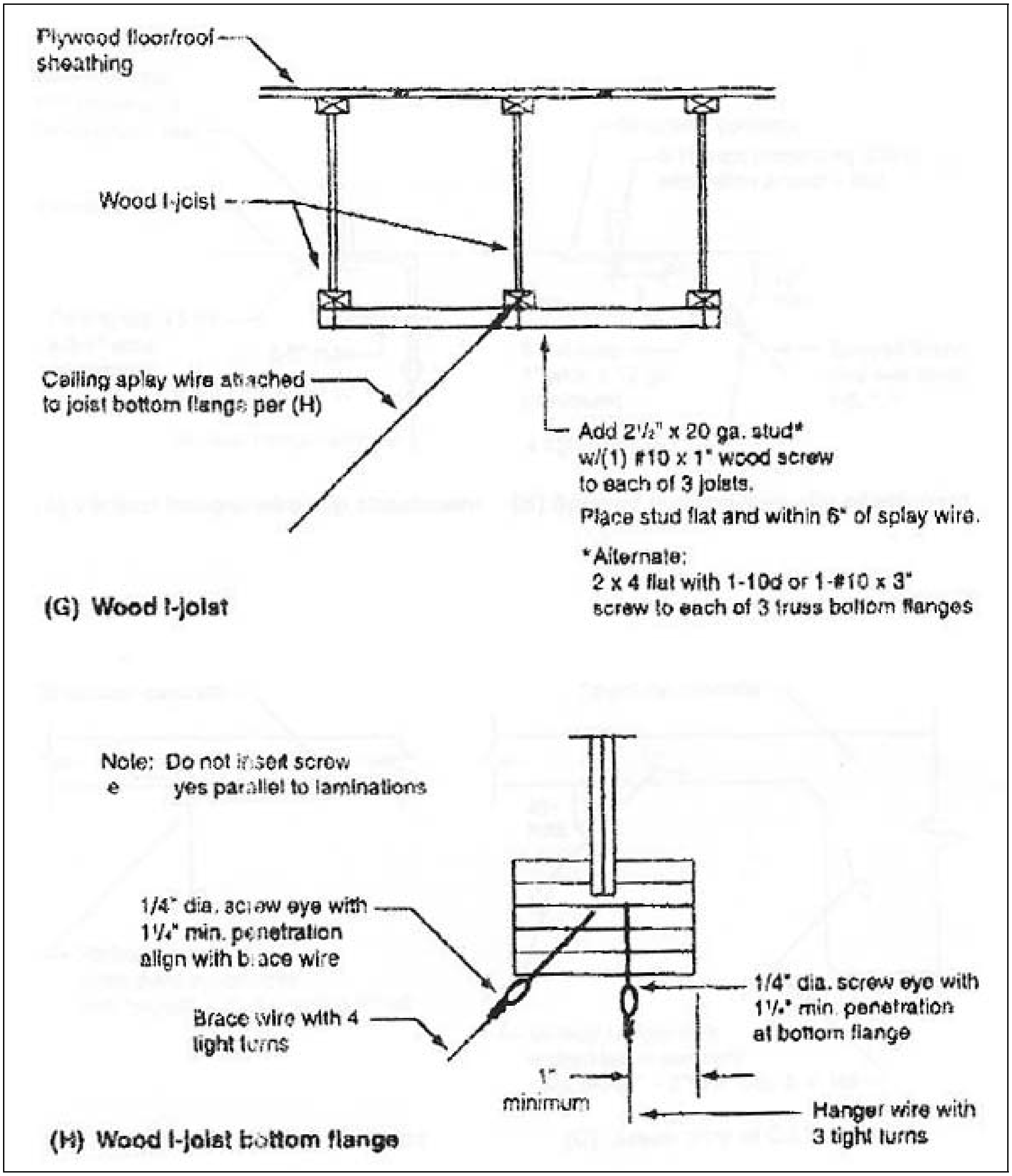


Figure 85. Hanger connection to wood frame